SCHOOL OF CIVIL ENGINEERING

INDIANA DEPARTMENT OF HIGHWAYS

JOINT HIGHWAY RESEARCH PROJECT

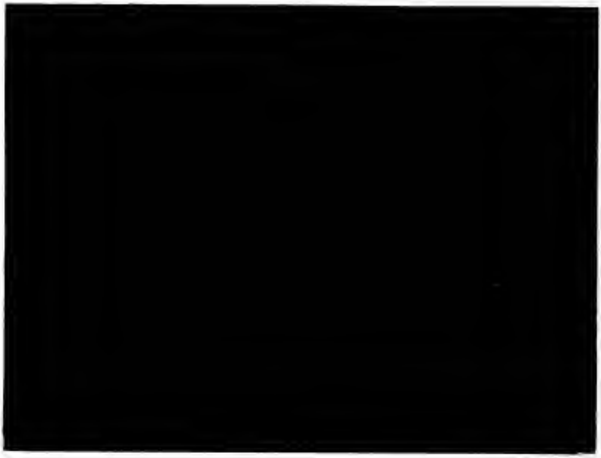
FHWA/IN/JHRP-86/4

Interim Report

THE DEVELOPMENT OF A PROCEDURE TO ASSESS HIGHWAY ROUTINE MAINTENANCE NEEDS

Fernando M. Montenegro
Kumares C. Sinha

PURDUE UNIVERSITY



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Interim Report

Executive Summary

DEVELOPMENT OF A PROCEDURE TO ASSESS HIGHWAY ROUTINE MAINTENANCE NEEDS

TO: H. L. Michael, Director
Joint Highway Research Project

FROM: K. C. Sinha, Research Engineer
Joint Highway Research Project

March 27, 1986
Revised October 21, 1987
Project No: C-36-63K

File: 9-7-11

Attached is the Interim Report on the HPR Part II Study entitled, "Assessment of Routine Maintenance Needs and Optimal Use of Routine Maintenance Funds." This report covers the Tasks A, B and C dealing with the development of foremen's condition survey procedure. A plan for implementation of the proposed procedure is included. The research was conducted by Fernando Montenegro under my direction.

This report is forwarded for review, comment and acceptance by the IDOH and FHWA as partial fulfillment of the objectives of the research.

Respectfully submitted,

K. C. Sinha
Research Engineer

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Interim Report

Executive Summary

DEVELOPMENT OF A PROCEDURE TO ASSESS HIGHWAY ROUTINE MAINTENANCE NEEDS

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16. Abstract

This is the first interim report covering the first three tasks of the study. This phase included the development of a procedure for the assessment of routine maintenance needs. The proposed procedure is based on unit foremen's evaluation of highway deficiencies. The validity of the proposed approach was tested in different randomly selected maintenance units. The research team objectively measured the distresses on those sections that were subjectively evaluated by the unit foremen. Both subjective and objective data together with estimations of expected work load by unit foremen provided the basis for statistical analyses of the proposed approach. The report includes a plan for implementation of the procedure.

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INTRODUCTION

One of the most important functions of a maintenance management system is to estimate the amount of maintenance work to be performed on various highway sections within a unit during a year or season. For the state highway system in Indiana, the budgeting for routine maintenance work is established primarily by subdistrict foremen on the basis of historical quantity standards and their judgment [1]. The procedure, used in most states, is based on Roy Jorgensen´s work in the 1960s [2,3]. However, this historical-empirical approach may not provide an assessment of actual needs by specific highway sections for scheduling of activities in the field.

A system is proposed in the present study for assessing routine maintenance work load based on a condition survey of roadways by unit foremen. It is believed that the proposed system will provide a tool that can effectively assist in the assessment of work loads by highway section. There can be several added benefits of the proposed procedure. Subdistricts and districts will be able to have a systematically gathered and uniformly defined maintenance needs data. Maintenance management at all levels can thus have another tool to check the maintenance levels-of-service throughout the state allowing maintenance policies to be consistent.

Maintenance Management Systems

The present versions of maintenance management systems in most states is primarily based on the development of appropriate standards. These standards are then used to control and plan various maintenance activities.

1. Quality standards are used to represent maintenance levels of service.

2. Quantity standards are the means by which inventory units are converted into work load. For example, if a certain network has 10 miles of bituminuous road, multiplying this by the quantity standard for shallow patching - such as 2 tons per mile of bituminuous road - will lead to the expected amount of shallow patching: 20 tons. Quantity standards are developed primarily from historical data as well as from input from the unit foremen. They are averages of past requirements per unit of inventory for each maintenance activity.

3. Performance standards help to translate expected work load per activity to man-hours, material and dollars per activity. They provide the average requirement of manpower and materials to accomplish one unit of a maintenance activity. Thus, having the work load per activity, we can multiply these quantities by their

respective performance standards and arrive at the requirements of labor and materials.

The Indiana Department of Highways (IDOH) _Management System Procedures Manual_ and the _Field Operations Manual_ provide a good insight into the maintenance management system in use in Indiana [4,5]. The procedure is based on the three sets of standards described earlier.

Condition Evaluation Procedures

Present condition survey procedures were mainly developed for pavement management systems, and they are directed to decisions regarding rehabilitation needs. However, in the present study it was necessary to develop a survey procedure that can identify conditions triggering routine maintenance needs. The proposed procedure is to conduct a visual condition survey by unit foremen on a periodic basis.

DEVELOPMENT OF THE PROPOSED APPROACH AND DESIGN OF EXPERIMENT

Development of the Condition Survey Form

A simple survey form was developed on the basis of current procedures and consultation with the unit foremen and subdistrict personnel. The selection of maintenance activities and condition distresses to be included in the

survey procedure was based on maintenance personnel´s opinion and information available in the literature on highway maintenance management. Table 1 shows the list of maintenance activities included in the study. The highway distresses considered in the survey are presented in Table 2.

Design of Experiment

The proposed approach was tested in field as to its validity and accuracy as well as to check if the survey form developed represented the actual typical condition of the roadways. The work elements included:

1. Collection of the highway physical condition information through a visual inspection by unit foremen. The type of visual inspection was the same as that currently used by the IDOH. The units were selected by stratified random sampling. The unit foremen were asked to generate two types of data: a subjective opinion about the degree of several deficiency conditions in the roadway stretch being analyzed and an estimate of the expected amount of work currently needed in the selected maintenance activities based on the condition of the roadway they are evaluating.

Table 1. Routine Maintenance Activities Included in the Study

Pavement	Unpaved Shdrs.	Drainage
201 Shallow Patching	210 Spot Repair Unpaved Shdrs.	231 Clean and Reshape Ditches
202 Deep Patching	211 Blading Shdrs.	234 Motor Patrol Ditching
203 Premix Leveling	212 Clipping Unpaved Shdrs.	
204 Full Width Shdr. Seal	213 Reconditioning Unpaved Shdrs.	
205 Seal Coating		
206 Sealing Long. Cracks and Joints		
207 Sealing Cracks		

Table 2. Highway Distresses Included in the Survey

Flexible Pavements	Rigid Pavements
Blow Ups	Blow Ups
Bumps	Bumps
Depressions	Condition of Long. Joints
Ditch Condition	Condition of Transv. Joints
Linear Cracks	Ditch Condition
Potholes	Linear Cracks
Raveling	Potholes.
Rutting	Raveling in Bit. Shldr
Shdr. Build Up	Shdr. Build Up
Shdr. Drop-Off	Shdr. Drop-Off
Shdr. Potholes	Shdr. Potholes
Surface Failures	Spalling
	Surface Failures

2. Objective measurements of different deficiency conditions by the research team on the same highway stretches surveyed by the unit foremen.

3. Statistical correlation and analysis of the data collected in Steps 1 and 2.

4. Development of the criteria that would relate the unit foremen's evaluation of a deficiency condition to a certain level of routine maintenance activity.

5. Analysis of the variability of the subjective opinions about the roadway condition. This analysis can then assist in identifying inconsistencies in maintenance decisions and provide a basis for reconciling differences.

The forms used included information on both roadway condition and estimated maintenance needs. Foremen were required to estimate the work load so that the information could be used to analyze the validity of the proposed approach. This part of the survey form will not be included in the form design to be used by field personnel at a later stage.

Statistical Selection of the Maintenance Units Surveyed

The study used a stratified random sampling scheme. A stratified random scheme is a restricted randomization

design in which the experimental units are first sorted into homogeneous groups or blocks and then the required number of experimental units is randomly selected within each group [6].

The study considered the northern, central and southern part of the State of Indiana as blocks, from which the units to be surveyed were selected. In this way, variations in climate and regional maintenance practices could be taken into account when analyzing the validity of the proposed approach. Three subdistricts were randomly selected in each of these three regions. Within each of these subdistricts, two randomly selected maintenance units were surveyed. In such a way, the variations associated with both unit foreman and subdistrict could be analyzed when assessing the accuracy of the proposed condition survey method. A total of eighteen maintenance units were included in the study. The survey covered asphalt and concrete highways in both interstate and state highway systems. A total of 965 lane miles was surveyed. The forms used to conduct the foremen's survey are shown in Figures 1 and 2.

Objective Measurement of Highway Distresses

The highway stretches surveyed by the unit foremen were also surveyed by the research team and the highway distresses observed were physically measured. This

DISTRICT________________ HIGHWAY | S | US | IS | No:________

SUBDISTRICT________________ FROM________________________

UNIT NO.________________ TO________________________

DATE________________ TRAFFIC | LOW | MED | HIGH |

DIRECTION | N | S | E | W |

ASPHALT PAVEMENTS						
TRAFFIC LANES AND PAVED SHOULDERS						
M	S	F	N	SLIGHT	POTHOLES	SHALLOW PATCHING .... tons
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
M	S	F	N	SLIGHT	CRACKS	CRACK SEALING .... gals
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		FULL WIDTH SHOULDER SEAL ...... ft. miles
M	S	F	N	SLIGHT	RAVELING	
M	S	F	N	MODERATE		SEAL COATING ...... lane miles
M	S	F	N	SEVERE		
M	S	F	N	BLOW UPS, BUMPS AND SURFACE FAILURES		DEEP PATCHING .... tons
M	S	F	N			
M	S	F	N			
M	S	F	N	SLIGHT	RUTTING, DIPS	LEVELING .... tons
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
UNPAVED SHOULDERS						
M	S	F	N	SLIGHT	BUILD-UP	CLIPPING .... shldr. miles
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
M	S	F	N	SLIGHT	POTHOLES	SPOT REPAIR (210) .... tons of agg.
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
M	S	F	N	SLIGHT	DROP-OFF	BLADING .... shldr. miles
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		RECONDTING .... shldr. miles
DRAINAGE						
P	F	G		DITCHES		DITCHING (231) ...... linear ft
						MOTOR PATROL DITCHING (234) .... ditch miles

Figure 1. Asphalt Pavement Condition Survey Form Used by the Foremen in the Study

DISTRICT ____________ HIGHWAY | S | US | IS | No. ________

SUBDISTRICT ____________ FROM ____________

UNIT NO. ____________ TO ____________

DATE ____________ TRAFFIC | LOW | MED | HIGH |

DIRECTION | N | S | E | W |

CONCRETE PAVEMENTS						
TRAFFIC LANES AND PAVED SHOULDERS						
M	S	F	N	SLIGHT	POTHOLES	SHALLOW PATCHING .... tons
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
M	S	F	N	BLOW UPS, BUMPS AND SURFACE FAILURES		DEEP PATCHING .... tons
M	S	F	N			
M	S	F	N			
P	F	G		LONGITUD. JOINTS		SEALING LONG. CRACKS & JOINTS ..... linear miles of cracks & joints
P	F	G		TRANSVERSE JOINTS		CRACK SEALING .... gals.
M	S	F	N	SLIGHT	CRACKS	
M	S	F	N	MODERATE		FULL WIDTH SHOULDER SEAL ...... ft miles
M	S	F	N	SEVERE		
M	S	F	N	RAVELING IN BITUMINOUS SHLDR		
UNPAVED SHOULDERS						
M	S	F	N	SLIGHT	BUILD-UP	CLIPPING .... shldr. miles
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
M	S	F	N	SLIGHT	POTHOLES	SPOT REPAIR .... tons of agg.
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
M	S	F	N	SLIGHT	DROP-OFF	BLADING .... shldr. miles
M	S	F	N	MODERATE		RECONDTNG .... shldr. miles
M	S	F	N	SEVERE		
DRAINAGE						
P	F	G		DITCHES		DITCHING (231) ...... linear ft
						MOTOR PATROL DITCHING (234) .... ditch miles

Figure 2. Concrete Pavement Condition Survey Form Used by the Foremen in the Study

measurement took place within no more than two days from the foremen's survey. Every highway stretch that a foreman evaluated was subsequently evaluated by measuring objectively its distresses. As the measurement took place within a short period of foremen's survey, the possibility of occurrence of any changes in the highway condition between the two evaluations was minimized. The form used to record the physical measurements of distress is shown in Figure 3.

ANALYSIS OF THE VALIDITY OF THE PROPOSED APPROACH

The subjective condition rating data were converted into a numerical scale so that quantitative statistical analysis methods could be used. A point estimation technique was applied for the conversion of the subjective category scale used during the field survey to a 0-10 numerical scale.

To analyze the data gathered, regression analyses were performed. Table 3 presents a summary of the results obtained. It shows the significance of the proposed approach in explaining the variability of maintenance work load for eight of the nine maintenance activities considered. The lack of significance in the case of Sealing Longitudinal Cracks and Joints can be attributed to the small sample size.

HIGHWAY CLASS & No : Typical sample unit No: length: dist:

HIGHWAY FEATURE/ DISTRESS	TRAFFIC LANES	PAVED SHOULDER
WIDTH	1 | 2 | 3 | ....ft	No | Yes ....ft ...ft
SURFACE TYPE	ASPHALT | CONCRETE	ASPHALT | CONCRETE
POTHOLES	lth | wth | depth	length | width | depth
LINEAR CRACKS	sealed | lth ..... wth .... unsealed | lth<1/8 | wth	sealed | lth ..... wth .... unsealed | lth<1/8 ..... wth .....
ALLIGATOR CRACKING	seal | patch L | M | H | sealed unsealed ft2	seal | patch L | M | H | sealed unsealed ft2
RAVELING	L | M | H | ft2	L | M | H | ft2
RUTTING	inside wheel in | outside wheel in	........in
DIPS CORRUG.	DEPTH | FT2	DEPTH | FT2
BLOW UPS	L | M | H | No FT2	L | M | H | No FT2
SPALLING	L | M | H | No FT2	L | M | H | No FT2
SURFACE FAILURE	L | M | H | depth FT2 edge?	L | M | H | depth FT2
BUMPS	L | M | H | depth FT	L | M | H | FT
LONG JOINTS	fault | L | M | H | No | sldge LMH No	fault | L | M | H | No | sldge LMH No
TRANSVERSE JOINTS	fault | L | M | H | No | sldge LMH No	fault | L | M | H | No | sldge LMH No
PATCHED SURFACE	L M H FT2	L M H FT2
LANE/SDR DROP OFF	length FT depth IN	out shder width ft
PAVSHDR/UNPSHDR DROP OFF	length FT depth IN	med shder width ft
BUILD UP	length FT depth IN dist from pav.shder	
POTHOLES	LENGTH WIDTH DEPTH	sod L M H length shape P F G lth dpth
DITCH	WIDTH FT DEPTH FT	REMARKS
DIRT DEBRIS	N F S M NO DITCH	
CLOGGED(SED.)	N F S M CEMENT DITCH	
VEGETATION	N F S M DITCH IN PRIVATE YARD	
EROSION	N F S M	
CROSS SECTION	GOOD (TRIANG.) BAD (SQ.)	

DAY: DISTRICT: SUBDISTRICT: UNIT:

Figure 3. Form Used to Record Typical Distresses During Field Measurements

Table 3. Tests for the Significance of the Approach and Subdistrict and Individual Estimator's Effects

Maintenance Activity	Approach (Related "Assessed" Distresses)			Subdistrict Effect			Individual Estimator's Effect		
	Significant at $\alpha = 0.05$	F	α	Significant at $\alpha = 0.05$	F	α	Significant at $\alpha = 0.05$	F	α
Shallow Patching	yes	6.98603 (4,41)*	<0.001	yes	2.9448 (8,50)	0.01 - 0.025	no	1.2666 (9,41)	> 0.1
Crack Sealing	yes	4.6951 (4,41)	0.001-0.005	yes	2.5729 (8,50)	0.01-0.025	no	1.7119 (9,41)	> 0.1
Deep Patching	yes	2.9663 (7,38)	0.01 - 0.025	no	0.8495 (8,47)	> 0.1	no	1.0688 (9,38)	>0.1
Premix Leveling	yes	2.9248 (3,32)	0.01 - 0.025	yes	2.3576 (8,41)	0.025-0.05	no	1.7193 (9,32)	>0.1
Sealing Longitudinal Cracks and Joints	no	49.3049** (3,1)	> 0.1	no	3.5725 (4,2)	> 0.1	no	4.3236 (1,1)	>0.1
Clipping Unpaved Shdrs.	yes	25.8952 (2,43)	< 0.001	no	1.6044 (8,52)	>0.1	no	1.3799 (9,43)	>0.1
Spot Repair Unpaved Shdrs.	yes	5.9417 (4,41)	< 0.001	no	1.9063 (8,50)	0.05 - 0.1	yes	2.4455 (9,41)	0.025-0.05
Blading Shdrs	yes	4.2549 (4,41)	0.005 - 0.01	no	1.7162 (8,50)	>0.1	yes	4.0648 (9,41)	0.001 - 0.005
Clean and Reshape Ditches	yes	26.7146 (1,44)	< 0.001	no	1.4627 (8,53)	> 0.1	yes	3.782 (9,44)	0.001 - 0.005

* Degrees of freedom

** Remember that the sample size is much smaller in this case, thus, the power of the tests is lower.

It can be seen in Table 3 that maintenance subdistricts showed a significant influence in the estimation of the work load of Shallow Patching, Crack Sealing and Premix Leveling at a level of significance of 0.05. Individual estimator´s influences were found significant in assessing the needs of Spot Repair Unpaved Shoulders, Blading Unpaved Shoulders and Cleaning and Reshaping Ditches. These results suggest that the amount of work in Spot Repair Unpaved Shoulders, Blading Unpaved Shoulders and Cleaning and Reshaping Ditches is particularly influenced by the personal judgment of unit foremen, while the amount of Shallow Patching, Crack Sealing and Premix Leveling are more subject to regional differences in maintenance materials, practices or standards. The influences of subdistricts and foremen should be further studied in order to achieve consistency in maintenance needs assessment.

<u>Work Load and Subjective Evaluation of Distresses</u>

A set of regression analyses was performed to relate routine maintenance work load with the subjective evaluation of distresses by unit foremen. The purpose of these analyses were:

1. To develop models that can be used to estimate routine maintenance work loads on the basis of subjective evaluation of roadway distresses.

2. To form the basis of the calculation of "present" quantity standards.

3. To know how much of the variability of estimated maintenance work loads can be explained by foremen's survey.

These points were addressed by a stepwise regression procedure that gives "best" models for each of the analyzed maintenance activities. The following was the model adopted.

$$y_i = a + \sum_{j=1}^{n_i} b_j X_{ij} \qquad (1)$$

where,

y_i = square root of expected work load per activity per lane-mile, shoulder-mile or ditch-mile;

a = constant;

b_j = regression parameters, $j=1,2,\ldots,n_i$;

x_{ij} = subjectively rated distresses (pothole frequency, pothole size, etc).

The variables listed in Table 4 were included in Equation 1 in the process of developing models to predict work load per activity. The "best" models arrived at are presented in Table 5.

Table 4. Variables Considered in the Development of Predictive Models

Maintenance Activity	"Assessed" Distresses Considered	
Shallow Patching	Frequency of Potholes (X_1) Severity of Potholes (X_2)	Frequency of Cracks (X_3) Severity of Cracks (X_4)
Crack Sealing	Frequency of Cracks (X_3) Severity of Cracks (X_4)	Frequency of Raveling (X_5) Severity of Raveling (X_6)
Deep Patching	Frequency of Potholes (X_1) Severity of Potholes (X_2) Frequency of Cracks (X_3) Severity of Cracks (X_4)	Frequency of Raveling (X_5) Severity of Raveling (X_6) Frequency of Bumps, Blow Ups, and Surface Failures (X_7)
Premix Leveling	Frequency of Ruts and Dips (X_8) Severity of Ruts and Dips (X_9)	Frequency of Bumps, Blow Ups, and Surface Failures (X_7)
Sealing Longitudinal Cracks and Joints	Frequency of Cracks (X_3) Severity of Cracks (X_4)	Condition of Longitudinal Joints (X_{10})
Clipping Unpaved Shrds.	Frequency of Build-Ups (X_{11})	Severity of Build-Ups (X_{12})
Spot Repair Unpaved Shrds.	Frequency of Potholes in Unpaved Shdr. (X_{13}) Severity of Potholes in Unpaved Shdr. (X_{14})	Frequency of Dropoff (X_{15}) Severity of Dropoff (X_{16})
Blading Shdrs.	Frequency of Potholes in Unpaved Shdr. (X_{13}) Severity of Potholes in Unpaved Shdr. (X_{14})	Frequency of Dropoff (X_{15}) Severity of Dropoff (X_{16})
Clean and Reshape Ditches	Condition of Roadside Ditches (X_{17})	

Table 5. Models for Prediction of Work Load

Maintenance Activity	"Best" Suited Models	R^2 (%)
Shallow Patching	$y' = 0.157 + 0.09253 X_1 + 0.10865 X_2$	37.15
Crack Sealing	$y' = 3.243 + 1.409 X_4$	36.54
Deep Patching	$y' = -0.362 + 0.1176 X_1 + 0.15267 X_7$	30.66
Premix Levelling	$y' = -1.339 + 0.219 X_8 + 0.459 X_9$	58.00
Sealing Long. Cracks and Joints	No significant model was developed due to the lack of sufficient sample size	—
Chipping Unpaved Shdrs.	$y' = -0.067 + 0.06746 X_{11} + 0.05793 X_{12}$	55.43
Spot Repair Unpaved Shdrs.	$y' = -0.004 + 0.21536 X_{13} + 0.26212 X_{16}$	31.30
Blading Shdrs.	$y' = 0.239 + 0.08648 X_{13}$	12.71
Clean and Reshape Ditches	$y' = 34.845 - 4.26425 X_{17}$	47.98

The variables X_1, X_2, ..., X_{17} are defined in Table 4

* $y' = y$ transformed $= y ** 0.5 =$ Square root of expected work load per lane mile, shoulder mile or ditch mile.

The R^2 values shown in Table 5 indicate the percent of the variability in work load estimates that can be explained by foremen's evaluation of distresses. Except for blading shoulders, the R^2 values are generally reasonable. Some factors that might have lowered the R^2 values obtained are: (1) the lack of full understanding by some foremen of the meaning of some distresses, like raveling, when rating the roads; (2) the lack of consistency in the speed at which the foremen evaluated the roads (10 to 55 mph); (3) the fact that some foremen rated the extent of certain distresses influenced by "non-typical" spots rather than based on the overall extent of those distresses over the highway stretches; (4) the fact that maintenance standards for certain activities are based on usage and experience rather than on established maintenance levels-of-service (for example, unpaved shoulders may be clipped once every five years instead of being clipped whenever the buildup is greater than a determined height); (5) the fact that some of the distresses evaluated trigger two or more maintenance options; for example, bumps may trigger either "Bumps Burning" or "Deep Patching", depending on severity; and (6) the fact that altogether different maintenance activities may be triggered only for a certain extent of a particular distress type and not always (for example, raveling can trigger either sealing or patching or major maintenance, depending on the extent and severity of the raveling). It

is believed that many of these items can be improved by training and thus the resulting future R^2 values can be increased. However, a note of caution should be given. The models developed in this section are statistical in nature. No mechanistic or cause-effect relationship between work load and "assessed" distresses was established.

Analysis of the Field Survey Data

This section presents a regression of maintenance work load per activity on related measured distresses. The objective was to highlight major distresses that need to be included in the survey form proposed for implementation. It should be noted that the extent of patched surface was found to be the only additional significant highway feature that contributed to the explanation of the variation in estimated needs of Premix Leveling.

Proposed Quantity Standards

The procedure proposed for use in estimating future routine maintenance needs involves an assessment of maintenance needs based on present needs determined by unit foremen's subjective evaluation of distrsses. The structure of the models used in the procedure allows their accuracy to be improved with the implementation of the foreman's survey suggesting the inclusion of additional distresses or

modified scales.

On the basis of the models developed in this study "present" quantity standards (QS) were computed for various combinations of highway distress frequency and severity. As an illustration, the following example can be considered. The QS for Shallow Patching in roadways assessed as having "Many" "Slight" potholes was calculated using the prediction model for Shallow Patching. In that model, expected Shallow Patching per lane mile is a function of the assessed frequency (x_1) and severity of potholes (x_2). The model was solved with the numerical values associated with the categories "Many" and "Slight" potholes, 8.01 and 1.79, respectively. The resulting QS-value can thus be computed as 1.20 tons per lane mile. Similar computations were done for other activities under various combinations of distress frequency and severity. The resulting QS-values are presented in Table 6.

PROPOSED PLAN FOR IMPLEMENTATION

The different steps that can be followed to implement the proposed approach are listed below.

1. Unit foremen would perform the condition survey in early fall and early spring each year. Condition data would be recorded for each highway stretch within the boundaries of a maintenance unit. One form should be

Table 6 Proposed "Present" Quantity Standards

Shallow Patching
(Tons per Lane Mile)

"Assessed" Pothole Severity \ "Assessed" Pothole Frequency	N	S	M
Sl	0.20	0.50	1.20
Mo	0.60	1.10	2.10
Se	1.20	1.90	3.10

Crack Sealing
(Gallons per Lane Mile)

"Assessed" Severity of Cracks

Sl	33.23
Mo	103.24
Se	212.73

Deep Patching
(Tons per Lane Mile)

"Assessed" Bumps, Blow-Ups and Surface Failure Frequency \ "Assessed" Pothole Frequency	N	S	M
N	0.0	0.04	0.50
S	0.10	0.50	1.30
M	0.90	1.70	3.25

Table 6 (Continued)

Premix Leveling
(Tons per Lane mile)

"Assessed" Severity of Rutting and Dips	"Assessed" Frequency of Rutting and Dips: N	S	M
Sl	0.13	0.34	1.53
Mo	1.13	4.07	7.12
Se	6.27	11.96	16.89

Clipping Unpaved Shdrs.
(Shdr. Miles per Shdr. Mile)

"Assessed" Severity of Buildups	"Assessed" Frequency of Buildups: N	S	M
Sl	0.01	0.10	0.33
Mo	0.07	0.25	0.60
Se	0.20	0.45	0.90

Spot Repair Unpaved Shdrs.
(Tons per Shdr. Mile)

"Assessed" Severity of Dropoff	"Assessed" Frequency of Potholes in Unpaved Shdr: N	S	M
Sl	0.40	1.70	4.80
Mo	2.00	4.45	9.10
Se	5.10	8 60	14.70

Table 6 (Continued)

		Blading Shdrs. (Shdr. Miles per Shdr. Mile)
"Assessed" Frequency of Potholes in Unpaved Shdrs	N	0.10
	S	0.30
	M	0.90

		Clean and Reshape Ditches (Ft per Ditch Mile)
"Assessed" Condition of Roadside Ditch	P	693.0
	F	190.0
	G	2.0

filled for each highway stretch. Figures 4 and 5 show the proposed forms for asphalt and concrete pavements. These forms are modified versions of the forms used in the study. Unlike the forms used in the study, the proposed forms include "patched area" as one of the distress indicators and a three-category scale is used for the frequency of distresses. The analysis conducted in the study indicated these changes would improve the survey results.

2. Unit foremen would drive along the entire stretch of a roadway at a reduced speed of about 30 mph before rating. It should be noted that the proposed survey was designed to be fast enough so that an entire highway stretch could be surveyed without resorting to sampling sections. In this manner, the foremen would base their judgment on the overall condition of the stretch. Only one combination of frequency and severity of particular deficiency conditions should be selected. For example, if a unit foreman thinks that there is extensive cracking of low severity in a highway stretch, he will mark the cell corresponding to "Many" "Slight" cracks.

3. An estimation of maintenance work load for each activity and for each highway stretch can be made by matching the condition data recorded on the forms in

DISTRICT ________________ HIGHWAY | S | US | IS | No. ____________

SUBDISTRICT ________________ FROM ________________

UNIT NO. ________________ TO ________________

DATE ________________ TRAFFIC | LOW | MED | HIGH |

DIRECTION | N | S | E | W |

ASPHALT PAVEMENTS				
TRAFFIC LANES AND PAVED SHOULDERS				
M	S	N	SLIGHT	POTHOLES
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	CRACKS
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	RAVELING
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	BLOW UPS, BUMPS AND SURFACE FAILURES	
M	S	N	SLIGHT	RUTTING, DIPS
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	PATCHED SURFACE
M	S	N	MODERATE	
M	S	N	SEVERE	
UNPAVED SHOULDERS				
M	S	N	SLIGHT	BUILD-UP
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	POTHOLES
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	DROP-OFF
M	S	N	MODERATE	
M	S	N	SEVERE	
DRAINAGE				
P	F	G	DITCHES	

Figure 4. Asphalt Pavement Form Proposed for Implementation

DISTRICT ____________ HIGHWAY [S | US | IS] No. ____________

SUBDISTRICT ____________ FROM ____________

UNIT NO. ____________ TO ____________

DATE ____________ TRAFFIC [LOW | MED | HIGH]

DIRECTION [N | S | E | W]

CONCRETE PAVEMENTS				
TRAFFIC LANES AND PAVED SHOULDERS				
M	S	N	SLIGHT	POTHOLES
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	BLOW UPS, SPALLING, BUMPS AND SURFACE FAILURES	
P	F	G	LONGITUD. JOINTS	
P	F	G	TRANSVERSE JOINTS	
M	S	N	SLIGHT	CRACKS
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	RAVELING IN BITUMINOUS SHLDR	
UNPAVED SHOULDERS				
M	S	N	SLIGHT	BUILD-UP
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	POTHOLES
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	DROP-OFF
M	S	N	MODERATE	
M	S	N	SEVERE	
DRAINAGE				
P	F	G	DITCHES	

Figure 5. Concrete Pavement Form Proposed for Implementation

Figures 4 and 5 during the spring survey with the appropriate "present" quantity standards given in Table 6. These quantity standards are function of the "assessed" levels of frequency and severity of distresses. For example, when a stretch has "Many" "Moderate" potholes, 2.05 tons of Shallow Patching for each lane mile of the stretch would be considered. Multiplying the corresponding "present" quantity standards by the number of lane miles, shoulder miles or ditch miles of the highway stretch, various maintenance work loads for each highway stretch would be obtained. The quantity estimation for Crack Sealing and Sealing Longitudinal Cracks and Joints should be based on the condition data gathered during the fall survey. This is because fall is most appropriate for evaluating the condition of cracks that would influence the amount of sealing required. The maintenance needs for any maintenance unit, subdistrict, district, or the state, can be computed by adding the needs for each road stretch within that area. The estimated work loads by highway sections can then be used to determine the actual work loads within a budget constraint.

4. The aggregation of the evaluation data per maintenance subdistrict would provide a periodic indication of the

overall condition of the highways within the subdistrict. These data can be used to check the effectiveness of different maintenance policies related to field work.

SUMMARY AND CONCLUSIONS

The principal objective of this study was to develop an approach that can be used primarily to determine how much of a routine maintenance activity can be performed on a highway section during a given time period subject to a given budgetary constraint. This approach is based on the subjective rating of highway distresses by maintenance unit foremen. Routine maintenance needs are connected to their immediate cause, highway deficiencies. It is envisioned that the implementation of this approach would give a more structured approach to maintenance planning, since maintenance needs estimation would be based on present needs.

This study developed both the methodology to perform the proposed foremen's surveys and the criteria to relate the subjective data obtained to certain levels of routine maintenance activities. In this connection, regression analyses allowed the development of estimation models for expected work load based on foremen's subjective evaluation of distresses. Finally, the concept of "present" quantity

standards were introduced. It should be noted, however, that before the procedure can be implemented further, work is necessary to establish increased consistency in foremen's evaluation of distress conditions and subsequent work load estimation.

The use of this approach can provide decision-makers with the information and tools to monitor the condition of the highway network. This can help not only to assess maintenance needs but also to check the efficiency and quality of maintenance field work.

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Interim Report

DEVELOPMENT OF A PROCEDURE TO ASSESS HIGHWAY ROUTINE MAINTENANCE NEEDS

TO: H. L. Michael, Director
Joint Highway Research Project

March 27, 1986
Revised October 21, 1987
Project No: C-36-63K

FROM: K. C. Sinha, Research Engineer
Joint Highway Research Project

File: 9-7-11

Attached is the Interim Report on the HPR Part II Study entitled, "Assessment of Routine Maintenance Needs and Optimal Use of Routine Maintenance Funds." This report covers the Tasks A, B and C dealing with the development of foremen's condition survey procedure. A plan for implementation of the proposed procedure is included. The research was conducted by Fernando Montenegro under my direction.

This report is forwarded for review, comment and acceptance by the IDOH and FHWA as partial fulfillment of the objectives of the research.

Respectfully submitted,

K. C. Sinha
Research Engineer

KCS/rrp

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Interim Report

DEVELOPMENT OF A PROCEDURE TO ASSESS HIGHWAY ROUTINE MAINTENANCE NEEDS

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Prepared as Part of an Investigation

Conducted by

Joint Highway Research Project
Engineering Experiment Station
Purdue University

in cooperation with the

Indiana Department of Highways

and the

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Purdue University
West Lafayette, Indiana
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15. Supplementary Notes

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16. Abstract

This is the first interim report covering the first three tasks of the study. This phase included the development of a procedure for the assessment of routine maintenance needs. The proposed procedure is based on unit foremen's evaluation of highway deficiencies. The validity of the proposed approach was tested in different randomly selected maintenance units. The research team objectively measured the distresses on those sections that were subjectively evaluated by the unit foremen. Both subjective and objective data together with estimations of expected work load by unit foremen provided the basis for statistical analyses of the proposed approach. The report includes a plan for implementation of the procedure.

17. Key Words Highway Routine Maintenance; Pavement and Shoulder Maintenance; Maintenance Management; Quantity Standards; Performance Standards; Condition Survey; Work Load Estimation	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

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TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (continued)

CHAPTER 1

INTRODUCTION

1.1 Introduction

In the 1980s, highway agencies are placing increasing emphasis on highway maintenance cost-effectiveness. Since higher maintenance budgets are not always available, efficient management of the available funds is important to agency managers.

To achieve efficiency in the use of highway funds, not only major but also routine maintenance activities should be considered. Routine maintenance, sometimes neglected by researchers, accounts for large amounts of state money every year. For example, the State of Indiana spent approximately 49 million dollars in self-performed highway routine maintenance activities in the 1985 fiscal year [1].

1.2 Background

Several tools have been developed to manage maintenance activities and to aid in fund allocation decision. Maintenance Management Systems (MM Systems) are comprehensive sets of these tools, with the purpose of directing and controlling routine maintenance activities. The essence of these systems is to provide a consistent procedure to establish priorities, scheduling and budgeting for an agency maintenance plan [2].

One of the most important functions of MM Systems is to estimate future work loads. The current state-of-the-art in routine maintenance needs assessment is based on Roy Jorgensen's work of the 1960s [3]. This system, used in most states, makes an assessment of routine maintenance needs on the basis of predefined performance and quantity standards. The quantity standards are primarily historical averages of expected work load of an activity per unit of inventory.

Specifically, in the case of Indiana [4], the work load is established as follows:

1. The subdistrict foremen report their expectation of future work per activity based on historical quantity standards and their judgment.

2. Personnel from the central office visit the different subdistricts to discuss these expected needs.

3. A Quantity Standard is calculated for each activity by the Central Office and the work load is predicted.

This historical-empirical method is usually based on past performance and may not provide an assessment of needs related to the current condition of the highways for all activities. The objective of the present study was to improve the needs assessment procedure so that a unified system of data collection and performance monitoring can be established.

1.3 Scope of the Research

The purpose of this research study was to develop an improved procedure for assessing highway routine maintenance needs that can be used by the Indiana Department of Highways. The research was carried out by the Joint Highway Research Project at Purdue University with the sponsorship of the Federal Highway Administration and the Indiana Department of Highways.

The proposed system for assessing highway routine

maintenance needs is based on a condition survey of roadways by unit foremen. The unit foremen would subjectively evaluate highway deficiency conditions that warrant routine maintenance needs. It is believed that the proposed system will lead to a uniform standardized approach to highway maintenance budgeting, since the allocation of funds can be based on requirements arrived at on the basis of specific needs rather than primarily on a historical basis. There can be several added benefits of the proposed procedure. Subdistricts and districts will be able to have a systematically gathered and uniformly defined maintenance needs data. Maintenance management at all levels can have another tool to check or compare with the maintenance levels-of-service throughout the state. Thus, maintenance policies can be consistent.

This report discusses the development of the proposed maintenance needs assessment system, as well as the study design of experiment used to test its accuracy and statistical reliability. It should be noted that a parallel study has been conducted on service life and cost of different maintenance activities [5]. These two studies will subsequently be incorporated in a general resource allocation model for determining the optimal level of routine maintenance expenditures.

1.4 Report Organization

This report consists of five chapters and two appendices. Chapter 2 discusses the different parts and characteristics of present Maintenance Management Systems as well as their relationships with Pavement Management Systems. A literature review on existing highway and pavement condition evaluation procedures is also presented.

Chapter 3 gives the theoretical background of the proposed needs assessment system. The development of the field survey form and the design of experiment used to test the validity and accuracy of the proposed procedure are discussed.

The analysis of the data gathered during the field survey is provided in Chapter 4. Statistical reliability tests are discussed and results presented. The relationship between estimated work load for each activity and the foremen´s evaluation of different deficiency conditions is discussed. Chapter 5 gives the summary and conclusions of the thesis.

Some observations on maintenance practices made during the field work of the present research are included in the Appendix. It is believed that they can be useful to avoid consistency problems in maintenance policy related to field work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents a discussion of a literature review on Maintenance Management Systems (MM Systems), with particular emphasis on highway condition evaluation procedures. The structure of MM Systems is relevant to this study, since the objective of the study is to improve one element of a MM System, the way in which the maintenance work load is estimated. In this connection, some of the characteristics of pavement management systems are also reviewed as they relate to condition evaluation procedures. Existing condition evaluation procedures were examined to provide background for the development of the routine maintenance condition survey proposed in this study.

2.2 Maintenance Management Systems

Maintenance Management Systems (MM Systems) are intended to answer among many others, the following questions pertinent to this study: (1) What type of maintenance should be done on existing highway systems ? (2) What sections need maintenance now or later ? (3) What alternatives are available ? (4) How much maintenance is needed ? MM systems are also used to provide consistent methodologies to establish priorities, and to schedule and budget highway routine and periodic major maintenance. In their broadest sense, they comprise [6, 7]:

1. Establishment of maintenance levels.
2. Development of performance standards.
3. Determination of work load.
4. Budgeting of resources to meet the predicted work load.
5. Scheduling of activities.
6. Establishment of procedures for management planning, evaluation and control.
7. Design of reports and records to serve the system.

The present version of the maintenance management systems in most states is primarily based on the development of appropriate standards. These standards are then used to control and plan various maintenance activities. A simplified diagram showing the key elements of a maintenance management system is shown in Figure 2.1. It can be noted that there are three sets of standards [7, 8, 9, 10], as discussed below.

1. Quality Standards: They answer the question of what represents a sufficiently maintained roadway. They are specific highway condition goals to be achieved through maintenance. It is through these standards that maintenance levels of service are established.

2. Quantity Standards: These are expressions of the expected amount of work for different maintenance activities per inventory unit.

3. Performance Standards: These are used in the establishment of the most cost-effective methods of accomplishing different maintenance activities. They also provide an expected rate of accomplishment per activity.

Two of these standards are particularly important: (1) Quantity Standards; and (2) Performance Standards.

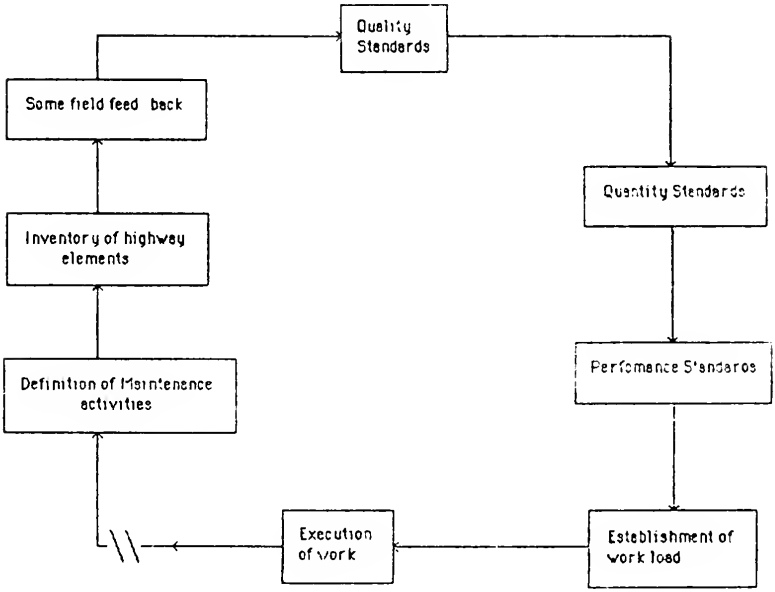


Figure 2.1 Functional Relationship among Various Maintenance Standards

Both provide the basis for budgeting and scheduling future maintenance work.

Quantity standards are the means by which inventory units are converted into work load. For example, if a certain network has 10 miles of bituminuous road, multiplying this by the quantity standard for shallow patching - such as 2 tons per mile of bituminuous road - will lead to the expected amount of shallow patching: 20 tons. Quantity standards may be developed from historical data or specific work study information. They are generally averages of past requirements per unit of inventory for each maintenance activity.

Performance standards help to translate expected work load per activity to man-hours, material and dollars per activity. They provide the average requirement of manpower equipment and materials to accomplish one unit of a maintenance activity. Thus, having the work load per activity, these quantities can be multiplied by their respective performance standards and requirements of men and material can be determined.

2.2.1 The Case of Indiana

The Indiana Department of Highways (IDOH) Management System Procedures Manual and the Field Operations Manual provide a good insight into the maintenance management system in use in Indiana [11, 12]. It was developed by Roy Jorgensen, Inc. in 1975 and the underlying approach was presented in 1972 [6]. The procedure is based on the three sets of standards described earlier.

Figure 2.2 shows an example of the performance standards that are in use in Indiana. Quantity standards are based on the empirical process explained in Section 1.2. As mentioned earlier, highway inventory units lead to work load by means of quantity standards and work load leads to budgets by means of performance standards.

2.3 Pavement Management Systems

There are several definitions of Pavement Management Systems (PM Systems) available in the literature [13, 14, 15]. The American Association of State Highway and Transportation Officials (AASHTO) Joint Task Force on Pavements states that Pavement Management is the effective and efficient directing of the various activities involved in providing and keeping pavements in an acceptable condition at the least life cycle cost, and that a Pavement Management System (PM System) is a documented procedure to

INDIANA DEPARTMENT OF HIGHWAYS
DIVISION OF MAINTENANCE

PERFORMANCE STANDARD

ACTIVITY	Sealing Cracks	CODE	207 PM

DESCRIPTION AND PURPOSE Cleaning and sealing open cracks and joints in bituminous and concrete roadways and paved shoulder surfaces to prevent the entry of moisture and debris which leads to surface and base failure. This activity also includes sealing short sections or isolated areas of alligatored, raveled, or spalled bituminous surfaces to prevent entry of moisture and further deterioration of the surface.

AUTHORIZED BY	Subdistrict	WORK CONTROL CATEGORY	Limited

SCHEDULING Perform on areas where there is loss of seal or cracking or the joint filler is broken, brittle or missing and allowing entry of water and foreign material. This work should be scheduled in the cooler months when contraction has opened the crack or joint. Do not cover painted lines or messages without prior approval of District Traffic.

CREW SIZE 11 MEN

WORK ASSIGNMENT	QTY.
Supervisor	1
Flagman	2
Pickup or Tractor Operator	2
Air Compressor Operator	1
Tar Kettle Spray Operator	1
Laborer	2
Truck Driver/Laborer	2

EQUIPMENT	QTY.
Pickup or Tractor/Air Compressor	1
Pickup or Tractor/Tar Kettle	1
Dump Truck	2
Pickup Truck	1
Pickup/Crew Cab	1

MATERIALS

Bituminous Material
Cover Aggregate

WORK METHOD

1. Place signs and other safety devices.
*2. Clean crack as required.
3. Apply bituminous material to cracks.
4. Squeegee material to force into cracks and surface voids.
5. Remove any surplus material.
6. Dust the area lightly with cover aggregate.
7. Remove signs and safety devices.

* When routing of the joint or crack on concrete surfaces is required before sealing, see Activity 219, Other Roadway and Shoulder Maintenance.

APPROVED BY:

K M Mellinger
CHIEF, DIVISION OF MAINTENANCE

D. W. Lucas
DEPUTY DIRECTOR HIGHWAY OPERATIONS

AVERAGE DAILY PRODUCTION 2 - 4 Lane Miles

EFFECTIVE DATE JULY 1, 1982

Figure 2.2 Example of IDOH Performance Standards

coordinate and carry on those activities [16]. Although PM Systems are intended to include planning, design, construction, maintenance and rehabilitation, most current versions are concerned mainly with rehabilitation strategies and do not cover routine maintenance.

2.4 Condition Evaluation Procedures

Present condition survey procedures were mainly developed for PM Systems, and so, the objective of these procedures is to identify highway conditions that trigger rehabilitation needs. However, in this study it was necessary to develop a condition survey procedure identifying conditions that trigger routine maintenance needs rather than rehabilitation needs.

Haas and Hudson [13] grouped highway evaluation procedures in the following categories:

1. Evaluation of pavement serviceability-overall performance.

2. Evaluation of pavement structural capacity with the aid of destructive and non-destructive tests.

3. Evaluation on pavement distress: condition surveys.

4. Evaluation of safety: skid-resistance evaluation

In the present study a literature review of highway condition survey procedures was conducted. This literature review provides the background for the development of the maintenance foremen´s visual survey procedure that this study investigates.

2.4.1 Review of Condition Evaluation Procedures

Condition surveys have been performed by different agencies for many years. However, a recent NCHRP report indicates that there appears to be no single method of making a condition survey [17]. Since condition survey information is used differently by different organizations, there is a large variation in the way surveys are performed, recorded and analyzed.

A possible classification of highway condition survey procedures is shown in Figure 2.3. There are surveys that include only an assessment of existing highway distresses while others combine this information with destructive and non-destructive testing , such as deflection and skid resistance measurements. Further subdivisions are shown in the figure. Those visual surveys that provide at least partial information useful for routine maintenance are

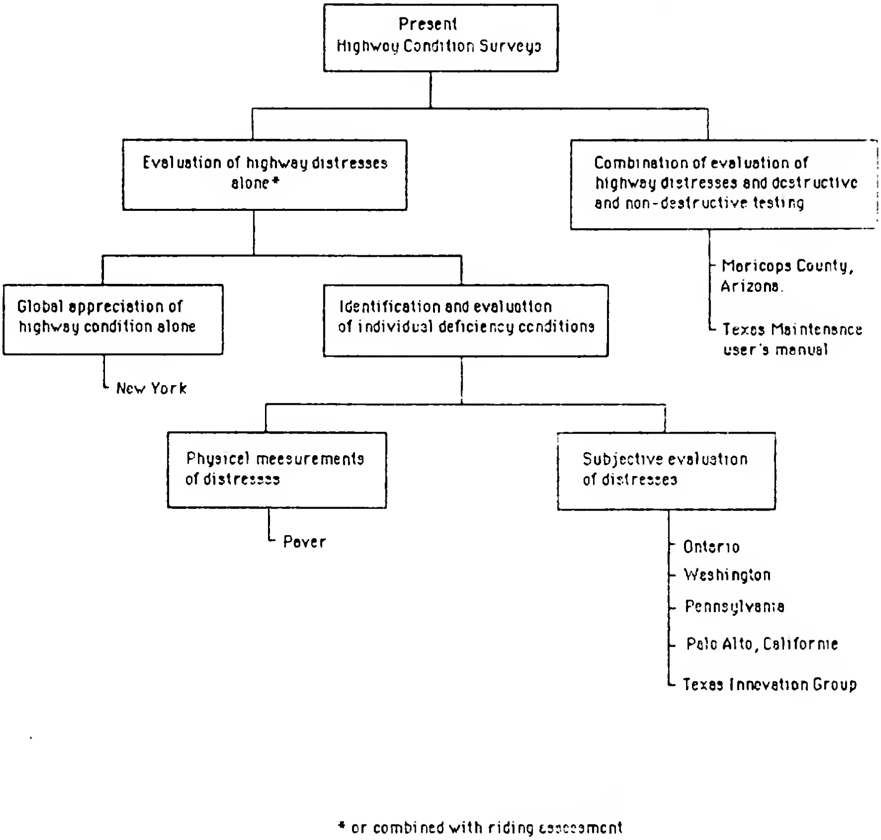


Figure 2.3 Classification of Highway Condition Survey Procedures

particularly relevant reference sources for the present study.

A brief description of the most pertinent survey procedures follows. Information about the other condition survey procedures listed in Figure 2.3 can be found in the literature [18, 19, 20].

The Washington Department of Transportation developed a pavement rating that combines ride quality and structural distress evaluation [21]. Structural defects are subjectively evaluated every other year on 200-ft sections per mile of road. A final rating that combines the ride and defect ratings is used for assessing the general condition of the roadways at the network level.

Pennsylvania's pavement condition survey was designed to provide information for identifying candidate projects for maintenance and improvement programs [22]. Subjective rating of deficiency conditions is the basis of the assessment. The entire length of the road is surveyed. Survey sections are approximately 2500 feet long. It covers pavement surface condition as well as shoulder condition and geometry.

Ontario bases the classification of highways on a pavement condition rating (PCR) that is a function of the overall riding quality and a visual inspection of the

distresses of the pavement [23, 24]. Two different forms for flexible and rigid pavements have been developed. The severity as well as the frequency of each distress type present is recorded. Only the pavement surface is considered.

The Texas Transportation Institute has established a method for conducting a visual evaluation of the roadway, including pavement, shoulder, roadside, drainage appurtenances and traffic service devices [25]. A sampling technique is used to select the sections of roadway to be measured. Condition of roadway and roadside is recorded for each section selected. A pavement rating score, a shoulder rating score, a drainage rating score and a traffic services rating score are then calculated for each roadway based on weight factors for severity, frequency and type of the present distresses. Mays meter measurements are also recorded. Although not specifically designed for routine maintenance, this survey technique provides useful information for a MM System since it provides condition information about the roadway and roadside as opposed to only the pavement surface.

The New York Department of Transportation has developed and implemented a straightforward windshield survey procedure for assessing pavement condition [26, 27]. A 0-10 visual scale is used. The raters compare the

condition of the road under study with some standard photographs and verbal descriptions and rate the sections accordingly. It covers only pavement surface characteristics. The information recorded is a single overall rating.

The United States Army Corps of Engineers has developed an exhaustive pavement management system (PAVER) for use at military installations [28]. This system has had extensive use. The severity and frequency of the distresses recorded during a condition survey determine the pavement condition index (PCI) of each roadway. This PCI is considered an overall measurement of the condition of the roadway. The extension and frequency of the highway distresses are physically measured rather than subjectively evaluated. Only the pavement surface is taken into account.

The Texas Innovation Group developed a condition survey technique to be used in a manual for setting maintenance priorities [29]. It is designed mainly to be used at the county level. The visual survey covers only pavement deficiencies. The information gathered by means of this survey together with a riding quality assessment forms the basis of the assessment of maintenance and reconstruction needs.

Table 2.1 shows the characteristics of current surface distress evaluation practices in several other states [9].

2.5 Chapter Summary

The objective of this chapter has been to provide background on three areas: Maintenance Management Systems (MM Systems), Pavement Management Systems (PM Systems), and condition evaluation procedures.

MM Systems are used to manage routine maintenance activities. The estimation of future work loads, one of the elements in a MM System, is based on historical or empirical quantity standards. The present study proposes a procedures based on maintenance foremen's highway condition visual surveys for determining routine maintenance needs.

Present PM Systems focus on rehabilitation strategies, and so do present condition survey procedures. Little attention has so far been given to developing a condition survey technique for assessing routine maintenance needs.

Table 2.1 Characteristics of Some Condition Survey Procedures in Use

ARIZONA	Primary evaluation consists of crack survey. Distress compared with standard photos. Other distress parameters determined to be too time-consuming. 1000 ft2 for each 1/3 mi is evaluated.
CALIFORNIA	Structural defects such as cracking, rutting, etc., rated for extent and severity. Entire state highway system rated on a biennial basis.
FLORIDA	Structural defects including rutting, cracking and patching are rated for 100-ft as representative of 1-mi sections. Defect rating (DR) is determined as part of overall evaluation.
UTAH	Detailed evaluation of cracking, rutting, patching, wear, weathering, etc., on 500-ft of 1-mi sections made from subjective analysis. Eleven parameters used.

CHAPTER 3

DEVELOPMENT OF THE PROPOSED APPROACH AND DESIGN OF EXPERIMENT

3.1 Introduction

Accuracy of the estimation of highway routine maintenance needs is important for an effective maintenance management program. This chapter describes a routine maintenance needs assessment system for maintenance work load estimation in the Indiana Department of Highway (IDOH). The design of experiment used to test the validity of the proposed maintenance assessment approach is also described in this chapter.

3.2 Proposed Approach

There are three levels involved in the structure of maintenance management in the IDOH: the Central Office, the District and the Subdistrict. Each of the subdistricts includes two to four maintenance units where

the actual field work takes place. The unit foremen are in charge of these maintenance units. Unit foremen not only direct the field work, but also, under the present maintenance management system (MMS), are in charge of reporting maintenance needs. Because of the nature of these responsibilities, the unit foremen generally have an intimate knowledge of the condition of the roadways in their units. Given the organizational background of the maintenance program in the IDOH, it is proposed that the assessment of routine maintenance needs be based on highway condition data systematically gathered in surveys conducted by maintenance unit foremen.

Figure 3.1 compares the present maintenance work load assessment procedure with the proposed one. The present system estimates maintenance work load based on quantity standards (QS) calculated from an empirical estimation of needs done by the subdistricts, that is supported on average past needs. The method proposed in this study is based on present highway condition data from which "present" QS is calculated. The development of these QS will be explained in Chapter 4.

It should be noted that the difference between the two systems lies only in the way the work load is calculated. Once the work load is established, the same performance standards are used to translate work load into

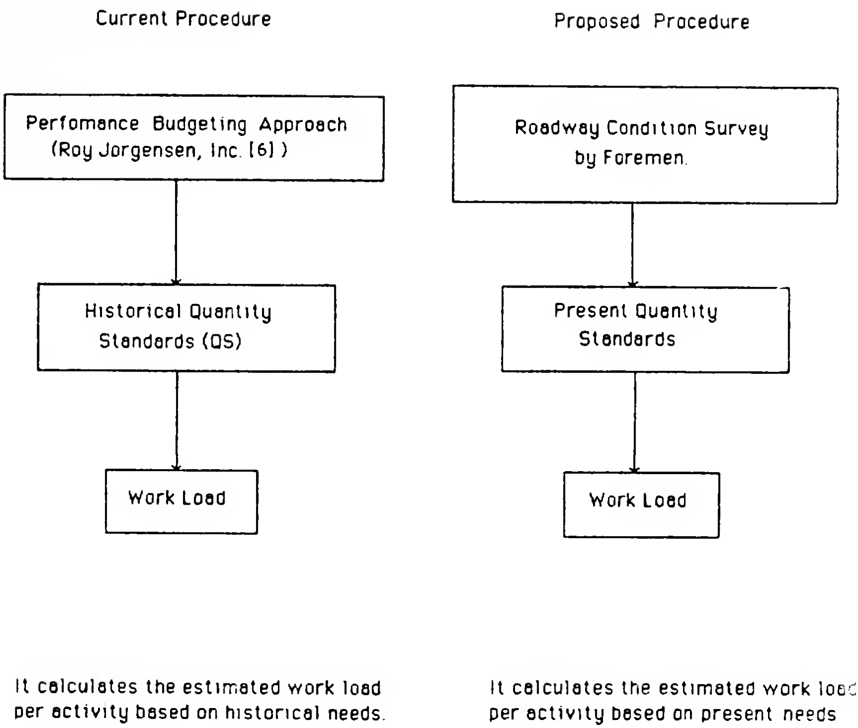


Figure 3.1 Comparison of the Current and Proposed Procedures for Determining Maintenance Work Loads

budgets. Thus, the proposed system implies only a localized change in Indiana's Maintenance Management System. The procedure has been made compatible with the overall IDOH MMS framework by depending on unit foremen for the formulation.

The benefits of the proposed approach, especially at the subdistrict and unit levels, are described below.

1. The procedure can allow a systematic collection of routine maintenance needs data.

2. It can help the maintenance foremen identify routine maintenance needs, set priorities on these needs and program the work in accordance with the resulting priorities.

3. The approach can provide a uniform method for deficiency identification. Proper identification of distresses will avoid inconsistencies in the selection of adequate maintenance treatments for each distress type since deficiences and maintenance treatments have a cause-effect relationship.

The expected benefits to be accrued at the District and Central Office levels follow:

1. The approach can improve the accuracy of the routine

maintenance needs assessment, and thus, it can help to make possible a comprehensive resource allocation process.

2. Maintenance budgets can be based on present needs rather than historical average needs.

3. Systematic data on roadway condition can be gathered. This will help better management and control of maintenance activities.

4. It can provide information for monitoring the performance of different materials used in maintenance as well as the quality of the work executed by diverse maintenance crews.

3.2.1 Characteristics of the Proposed Condition Survey Procedure

The condition survey procedure is the basis of the method for assessment of maintenance needs. The survey procedure was designed specifically for routine maintenance needs evaluation. As it was explained in Chapter 2, the state-of-the-art in condition evaluation refers mainly to survey methods to evaluate rehabilitation needs. Currently, IDOH maintenance management procedure uses a Maintenance Needed Report, Form No. MM-326 to record needed maintenance [12]. The characteristics of

the proposed evaluation procedure are presented below:

1. The evaluation procedure was designed to be simple and direct while providing more detail on road condition than Form No. MM-326. It is hoped to minimize the extra burden on maintenance field staff. It is believed that the visual condition survey will require one to one and a half days of the unit foremen's time.

2. It is recommended that the survey be performed twice a year, in early spring and in early fall. Early spring is most appropriate for recording potholes and other distresses which may become more noticeable after the thaw. Fall is most appropriate to evaluate cracks that influence the amount of preventive routine maintenance required. A six-month interval was selected since, given the level of expertise of the unit foremen, it is expected that most activity work loads can be anticipated with reasonable accuracy six months in advance.

3. The survey will include the total length of state roadways. There are two reasons for not proposing any random sampling technique: (1) deficiency conditions vary greatly among different parts of a highway; and (2) the recommended procedure is fast

enough.

4. Condition data would be recorded for each stretch of a state highway within the limits of a maintenance unit. One form would be used for each stretch.

5. It is recommended that the unit foreman drives the complete roadway stretch once at a reduced speed. A speed of about 30 mph was suggested in the literature [24] and it was found satisfactory in the present study. Upon completing the visual survey, the unit foreman can record his subjective evaluation of the roadway condition on the survey forms.

3.2.2 Development of the Condition Survey Form

Figure 3.2 shows the procedure that was followed to develop a condition survey form. A list of routine maintenance activities to be covered by the present research study was selected. Then, highway distresses that trigger any of the selected maintenance activities, were identified. The final selection of the condition distresses to be included in the survey procedure was based on maintenance personnel´s opinion and present literature on highway management.

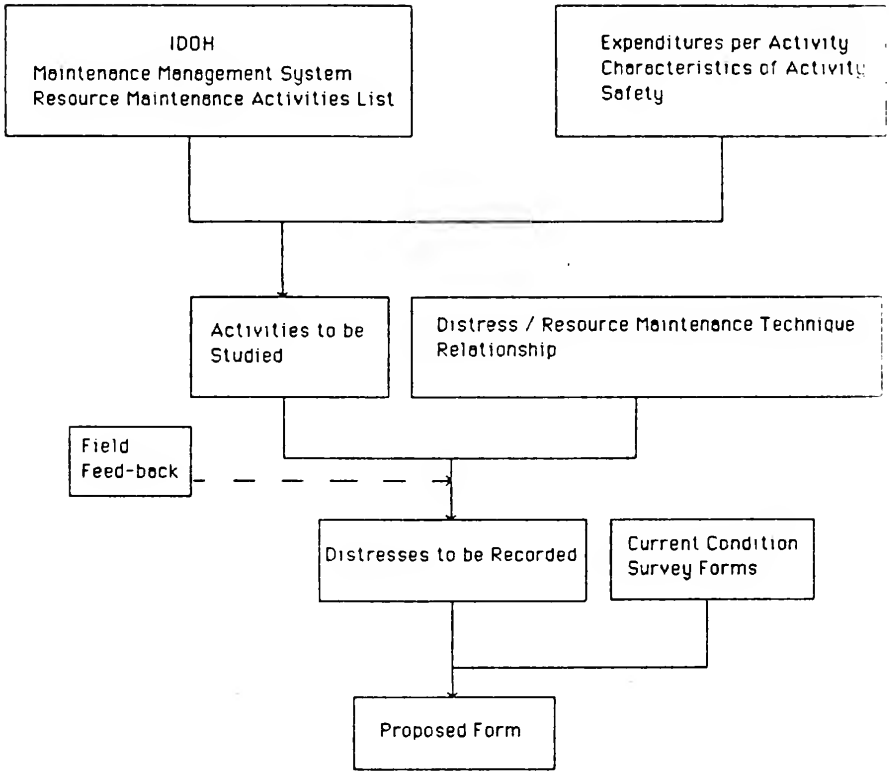


Figure 3.2 Development of the Condition Survey Form

3.2.2.1 Routine Maintenance Activities to Be Included in the Survey Procedure. A complete list of the Indiana Department of Highway's routine maintenance activities is presented in Figure 3.3 [11]. A group of these activities was selected to be included in the present study. This selection was made in consultation with maintenance personnel from four subdistricts. The factors and criteria used to select the activities to be studied were: amount of expenditure per activity and safety. Also, from the nature of the proposed survey and the level of expertise at unit foreman level, it was felt that certain activities and scenarios could not be anticipated six months in advance. Therefore, some activities were excluded such as snow and ice removal. The final list of maintenance activities included in the study is shown in Table 3.1.

3.2.2.2 Types of Distresses. Table 3.2 shows a table developed by Shahin [28], indicating the relationships between highway distresses and associated maintenance techniques. Several other tables that relate distresses with maintenance activities are found in the literature [6, 9, 30, 31, 32].

Based on these tables, highway distresses that would trigger the routine maintenance activities included in the study were identified. In this process, the following

LIST OF WORK ACTIVITIES, CODES, AND WORK MEASUREMENT UNITS BY ACTIVITY GROU

ACTIVITY NUMBER	ACTIVITY NAME	WORK MEASUREMENT UNIT
200-Roadway and Shoulder Maintenance Activities		
201	Shallow Patching	Tons of Premix
202	Deep Patching	Tons of Premix
203	Premix Leveling	Tons of Premix
204	Spot Seal Patching	Gallons of Bituminous Material
205	Seal Coating	Lane Miles
206	Sealing Longitudinal Cracks and Joints	Linear Miles
207	Sealing Cracks	Gallons of Bituminous Material
208	Filling Cracks and Joints	Gallons of Bituminous Material
209	Cutting Relief Joints	Linear Feet
210	Spot Patching Unpaved Shoulders	Tons of Aggregate
211	Blading Unpaved Shoulders	Shoulder Miles
212	Clipping Unpaved Shoulders	Shoulder Miles
213	Recondition Unpaved Shoulders	Shoulder Miles
219	Other Roadway and Shoulder Maintenance	Manhours
220-Roadside Maintenance Activities		
221	Machine Mowing	Swath Miles
222	Brush Cutting and Tree Trimming	Manhours
223	Herbicide Treatment	Gallons of Mixture
224	Seeding and Fertilizing	Manhours
229	Other Roadside Maintenance	Manhours
230-Drainage Maintenance Activities		
231	Clean and Reshape Ditches	Linear Feet
232	Inspect and Clean Minor Drainage Structures	Locations Cleaned/ Inspected
233	Pipe Replacement	Linear Feet
239	Other Drainage Maintenance	Manhours
240-Bridge Maintenance Activities		
241	Cleaning Bridge Decks	Decks Cleaned
242	Sealing Bridge Decks	Square Yards
243	Bridge Repair	Manhours
244	Bridge Repair by Contract	
245	Bridge Painting by Contract	
249	Other Bridge Maintenance	Manhours
250-Traffic Control Maintenance Activities		
251	Subdistrict Sign and Signal Maintenance	Sign/Signal Repaired
252	District Sign Maintenance	Manhours
253	District Sign Replacement	Signs Replaced
254	District Signal Maintenance	Manhours
255	Paint Centerlines	Centerline Miles
256	Paint Edgelines	Edgeline Miles
257	Paint Pavement Messages	Manhours
258	Guardrail Maintenance	Linear Feet
259	Other Traffic Control	Manhours

Figure 3.3 IDOH's Routine Maintenance Activities [11]

LIST OF WORK ACTIVITIES, CODES, AND WORK MEASUREMENT UNITS BY ACTIVITY GROUP

ACTIVITY NUMBER	ACTIVITY NAME	WORK MEASUREMENT UNIT
260-Winter and Emergency Maintenance Activities		
261	Emergency Maintenance	Manhours
262	Road Patrol	Manhours
263	Snow and Ice Removal	Manhours
264	Post Storm Cleanup	Manhours
265	Stockpile Winter Materials	Manhours
266	Winter Night Patrol	Manhours
269	Other Winter Maintenance	Manhours
270-Public Service Activities		
271	Rest Area Attendant	Manhours
272	Roadside Park, Rest Area, and Weigh Station Maintenance	Manhours
273	Work for Dept. of Natural Resource	Manhours
274	Work for State Institutions	Manhours
275	Full Width Litter Pickup	Right-of-way Pass Mile
276	Spot Litter Pickup	Manhours
277	Sweeping and Cleaning	Manhours
278	Liftbridge Attendant	Manhours
279	Other Service Activities	Manhours
280-Support Activities		
281	Equipment Repair & Maintenance	Manhours
282	Traffic Shop Operations	Manhours
283	Building and Grounds Maintenance	Manhours
284	Materials Handling and Storage	Manhours
288	TST "On Call" Time	Manhours
289	Other Support Activities	Manhours
290-Special Maintenance Activities		
291	Minor Surface and Shoulder Improvements	Manhours
292	Minor Roadside Improvements	Manhours
293	Minor Drainage Improvements	Manhours
294	Minor Bridge Improvements	Manhours
295	Minor Traffic Improvements	Manhours
Other Activities		
112	Field Maintenance Supervision	Manhours
117	Training	Manhours
120	Standby Time	Manhours

Figure 3.3 (Continued)

Table 3.1 Routine Maintenance Activities Included in the Study

Pavement	Unpaved Shdrs.	Drainage
201 Shallow Patching	210 Spot Repair Unpaved Shdrs.	231 Clean and Reshape Ditches
202 Deep Patching	211 Blading Shdrs.	234 Motor Patrol Ditching
203 Premix Leveling	212 Clipping Unpaved Shdrs.	
204 Full Width Shdr. Seal	213 Reconditioning Unpaved Shdrs.	
205 Seal Coating		
206 Sealing Long. Cracks and Joints		
207 Sealing Cracks		

Table 3.2 Pavement and Shoulder Distresses and Associated Maintenance Options [28]

Distress Type \ M&R Method	Do Nothing	Crack Seal	Partial Depth Patch	Full Depth Patch	Skin Patch	Pothole Filling	Apply Heat & Roll Sand	Apply Surface Seal Emulsion	Apply Rejuvenation	Apply Aggregate Seal Coat	Notes
1 Alligator Cracking			M,H	M,H				L	L		
2 Bleeding	L						L,M,H				
3 Block Cracking	L	L,M,H							L	L,M	
4 Bumps & Sags	L		M,H	M,H	M,H						
5 Corrugation	L		M,H	M,H							
6 Depression	L		M,H	M,H	M,H						
7 Edge Cracking	L	L,M	M,H	M,H							If predominant, apply shoulder seal, e.g., aggregate seal coat
8 Joint Reflective Cracking	L	L,M,H	H								
9 Lane/ Shoulder Drop Off	L										If predominant, level off shoulder and apply aggregate seal coat
10 Longitudinal Transverse Cracking	L	L,M,H	H					L	L	L,M	
11 Patching & Utility Cut	L	M	H*	H*							*Replace patch
12 Polished Aggregate	A									A	
13 Potholes			L	L,M,H		L,M,H					
14 Railroad Crossing	L				L,M,H						
15 Rutting	L		L,M,H	M,H	L,M,H						
16 Shoving	L		M,H								
17 Slippage Cracking	L	L	M,H								
18 Swell	L			M,H							
19 Weathering & Raveling	L		H					L,M	L	M,H	

Note: L = low severity; M = medium severity; H = high severity; A = has only one severity level.

factors were considered:

1. Consistency in the definition of different highway distresses was maintained by the use of only one set of definitions, summarized by the Federal Highway Administration [33].

2. The difference in maintenance activity definitions used in the literature and IDOH´s definitions [12] was taken into account.

3. The terms that are used by maintenance field personnel in Indiana to define different maintenance activities and deficiency conditions were utilized.

4. Highway conditions that trigger shoulder and drainage maintenance activities and not only pavement maintenance activity were included.

Table 3.3 shows the list of highway distresses selected for the present study.

3.2.2.3 Scales. As in the case of Pennsylvania and Texas condition survey forms [22, 25], a four-category scale for the frequency and a three-category scale for the severity of highway distresses were selected. It is believed that these scales would provide sufficient information, while keeping the complexity of the form to a minimum.

Table 3.3 Highway Distresses Included in the Survey

Flexible Pavements	Rigid Pavements
	Blow Ups
Blow Ups	Bumps
Bumps	Condition of Long. Joints
Depressions	Condition of Transv. Joints
Ditch Condition	Ditch Condition
Linear Cracks	Linear Cracks
Potholes	Potholes.
Raveling	Raveling in Bit. Shldr
Rutting	Shdr. Build Up
Shdr. Build Up	Shdr. Drop-Off
Shdr. Drop-Off	Shdr. Potholes
Shdr. Potholes	Spalling
Surface Failures	Surface Failures

3.2.2.4 The Forms. The recommended forms to be used in the proposed "condition survey" approach are shown in Figures 3.4 and 3.5. Separate forms are recommended for asphalt-surfaced and concrete-surfaced pavements. The forms can be modified to reflect the experience gained in the present study before the procedure is implemented by the IDOH.

3.3 Design of Experiment

The proposed approach was tested in the field as to its validity and accuracy as well as to check if the survey form developed captured the typical condition of the roadways. The work elements included:

1. Collection of the highway physical condition information through visual inspection by the unit foremen. The type of visual inspection was the same as that currently used by the IDOH. The units were selected by stratified random sampling. The unit foremen were asked to generate two types of data: a subjective opinion about the degree of several deficiency conditions in the roadway stretch being analyzed, and an estimate of the expected amount of work of selected maintenance activities during the coming six months, based on the condition of the roadway they are evaluating.

DISTRICT............................ HIGHWAY | S | US | IS | No ....

SUBDISTRICT............................ FROM............................

UNIT No............................ TO............................

DATE............................ TRAFFIC | Low | Med. | High |

DIRECTION | N | S | E | W |

ASPHALT PAVEMENTS					
TRAFFIC LANES AND PAVED SHOULDERS					
M	S	F	N	SLIGHT	POTHOLES
M	S	F	N	MODERATE	
M	S	F	N	SEVERE	
M	S	F	N	SLIGHT	CRACKS
M	S	F	N	MODERATE	
M	S	F	N	SEVERE	
M	S	F	N	SLIGHT	RAVELING
M	S	F	N	MODERATE	
M	S	F	N	SEVERE	
M	S	F	N	BLOW UPS, BUMPS AND SURFACE FAILURES	
M	S	F	N	SLIGHT	RUTTING, DIPS
M	S	F	N	MODERATE	
M	S	F	N	SEVERE	
UNPAVED SHOULDERS					
M	S	F	N	SLIGHT	BUILD - UP
M	S	F	N	MODERATE	
M	S	F	N	SEVERE	
M	S	F	N	SLIGHT	POTHOLES
M	S	F	N	MODERATE	
M	S	F	N	SEVERE	
M	S	F	N	SLIGHT	DROP -OFF
M	S	F	N	MODERATE	
M	S	F	N	SEVERE	
DRAINAGE					
P	F	C	DITCHES		

Figure 3.4 Condition Survey Form for Asphalt Pavements

DISTRICT.. .....

SUBDISTRICT.. .....

UNIT No.. ..

DATE.. ......

HIGHWAY | S | US | IS | No ....

FROM..

TO...

TRAFFIC | Low | Med. | High |

DIRECTION | N | S | E | W |

CONCRETE PAVEMENTS					
TRAFFIC LANES AND PAVED SHOULDERS					
M	S	F	N	SLIGHT	POTHOLES
M	S	F	N	MODERATE	
M	S	F	N	SEVERE	
M	S	F	N	BLOW UPS, SPALLING, BUMPS, AND SURFACE FAILURES	
P	F	G		LONGITUD. JOINTS	
P	F	G		TRANSVERSE JOINTS	
M	S	F	N	SLIGHT	CRACKS
M	S	F	N	MODERATE	
M	S	F	N	SEVERE	
M	S	F	N	RAVELING IN BITUMINOUS SHLDR	
UNPAVED SHOULDERS					
M	S	F	N	SLIGHT	BUILD - UP
M	S	F	N	MODERATE	
M	S	F	N	SEVERE	
M	S	F	N	SLIGHT	POTHOLES
M	S	F	N	MODERATE	
M	S	F	N	SEVERE	
M	S	F	N	SLIGHT	DROP -OFF
M	S	F	N	MODERATE	
M	S	F	N	SEVERE	
DRAINAGE					
P	F	G		DITCHES	

Figure 3.5 Condition Survey Form for Concrete Pavements

2. Objective measurements of the different deficiency conditions by the research team on the same highway stretches surveyed by the unit foremen.

3. Statistical correlation and analysis of the data collected in Steps 1 and 2.

4. Development of the criteria that would relate the unit foremen´s evaluation of a deficiency condition to a certain level of routine maintenance activity.

5. Analysis of the variability of the subjective opinions of the roadway condition. This analysis assisted in determining the consistency of condition assessment and the basis for improving future maintenance decisions.

The first item is discussed in Section 3.3.1 and the second is discussed in Section 3.3.2. Chapter 4 presents the third, fourth and fifth items.

3.3.1 Condition Survey

For the purpose of this research the unit foremen were required not only to give their opinion of the roadway condition but also an estimated work load per maintenance activity for the following six months. Knowing the future work load per activity, the ability of

the proposed condition survey approach to assess maintenance needs could be evaluated. Estimated work load was considered because the ultimate use of the proposed approach would be to prepare future maintenance budgets.

The forms used for asphalt and concrete pavements are shown in Figures 3.6 and 3.7. The forms included information on both the roadway condition as well as estimated maintenance needs. The estimation of future work load was only required for the purpose of developing appropriate quantity standards. In the present study and future survey forms to be used in implementing the procedure would not include this part.

3.3.1.1 <u>Statistical Selection of the Maintenance Units Surveyed</u>. This research used a stratified random sampling scheme. A stratified random scheme is a restricted randomization design in which the experimental units are first sorted into homogeneous groups or blocks and then the required number of experimental units is randomly selected within each group [34].

The northern, central and southern part of the State of Indiana were considered as blocks from which the units to be surveyed were selected. In this way, variations in climate and regional maintenance practices could be taken into account when analyzing the validity of the proposed

DISTRICT ______ HIGHWAY [S] [US] [IS] No: ______

SUBDISTRICT ______ FROM ______

UNIT NO. ______ TO ______

DATE ______ TRAFFIC [LOW] [MED] [HIGH]

DIRECTION [N] [S] [E] [W]

ASPHALT PAVEMENTS						
TRAFFIC LANES AND PAVED SHOULDERS						
M	S	F	N	SLIGHT	POTHOLES	SHALLOW PATCHING .... tons
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
M	S	F	N	SLIGHT	CRACKS	CRACK SEALING .... gals
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		FULL WIDTH SHOULDER SEAL ...... ft. miles
M	S	F	N	SLIGHT	RAVELING	
M	S	F	N	MODERATE		SEAL COATING ...... lane miles
M	S	F	N	SEVERE		
M	S	F	N	BLOW UPS, BUMPS AND SURFACE FAILURES		DEEP PATCHING .... tons
M	S	F	N			
M	S	F	N			
M	S	F	N	SLIGHT	RUTTING, DIPS	LEVELING .... tons
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
UNPAVED SHOULDERS						
M	S	F	N	SLIGHT	BUILD-UP	CLIPPING .... shldr. miles
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
M	S	F	N	SLIGHT	POTHOLES	SPOT REPAIR (210) .... tons of agg.
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
M	S	F	N	SLIGHT	DROP-OFF	BLADING .... shldr. miles
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		RECONDTING .... shldr. miles
DRAINAGE						
P	F	G	DITCHES			DITCHING (231) ...... linear ft
						MOTOR PATROL DITCHING (234) .... ditch miles

Figure 3.6 Asphalt Pavement Condition Survey Form Used by the Foremen in the Study

DISTRICT ____________ HIGHWAY | S | US | IS | No. ________

SUBDISTRICT ____________ FROM ____________

UNIT NO. ____________ TO ____________

DATE ____________ TRAFFIC | LOW | MED | HIGH |

DIRECTION | N | S | E | W |

CONCRETE PAVEMENTS						
TRAFFIC LANES AND PAVED SHOULDERS						
M	S	F	N	SLIGHT	POTHOLES	SHALLOW PATCHING .... tons
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
M	S	F	N	BLOW UPS, BUMPS AND SURFACE FAILURES		DEEP PATCHING .... tons
M	S	F	N			
M	S	F	N			
P	F	G	LONGITUD. JOINTS			SEALING LONG. CRACKS & JOINTS ...... linear miles of cracks & joints
P	F	G	TRANSVERSE JOINTS			CRACK SEALING .... gals.
M	S	F	N	SLIGHT	CRACKS	
M	S	F	N	MODERATE		FULL WIDTH SHOULDER SEAL ...... ft miles
M	S	F	N	SEVERE		
M	S	F	N	RAVELING IN BITUMINOUS SHLDR		
UNPAVED SHOULDERS						
M	S	F	N	SLIGHT	BUILD-UP	CLIPPING .... shldr. miles
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
M	S	F	N	SLIGHT	POTHOLES	SPOT REPAIR .... tons of agg.
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
M	S	F	N	SLIGHT	DROP-OFF	BLADING .... shldr. miles
M	S	F	N	MODERATE		RECONDTNG .... shldr. miles
M	S	F	N	SEVERE		
DRAINAGE						
P	F	G	DITCHES			DITCHING (231) ...... linear ft
						MOTOR PATROL DITCHING (234) .... ditch miles

Figure 3.7 Concrete Pavement Condition Survey Form Used by the Foremen in the Study

approach. Three subdistricts were randomly selected in each of these three regions. Within each of these subdistricts, two randomly selected maintenance units were surveyed. Thus, the variations associated with both unit foreman and subdistrict could be analyzed when assessing the accuracy of the proposed condition survey method. Figure 3.8 shows the three regions in Indiana, North, Central and South, as well as the subdistricts that were sampled.

The survey covered asphalt and concrete highways in both interstate and state highway systems. A total of 965 lane miles was surveyed. Figure 3.9 shows the structure of the sampling used and indicates the subdistricts, maintenance units and highway stretches surveyed.

3.3.2 Objective Measurement of Highway Distresses

The highway stretches surveyed by the unit foremen were also surveyed by the research team and the highway distresses observed were physically measured. This measurement took place within no more than two days from the foremen's survey. Every highway stretch that a foreman evaluated was subsequently evaluated by measuring objectively its distresses. As the measurement took place within a short period of foremen's survey, the possibility of any changes in the highway condition between the two

Figure 3.8 North, Central and South Regions in Indiana and Sudistricts Included in the Study

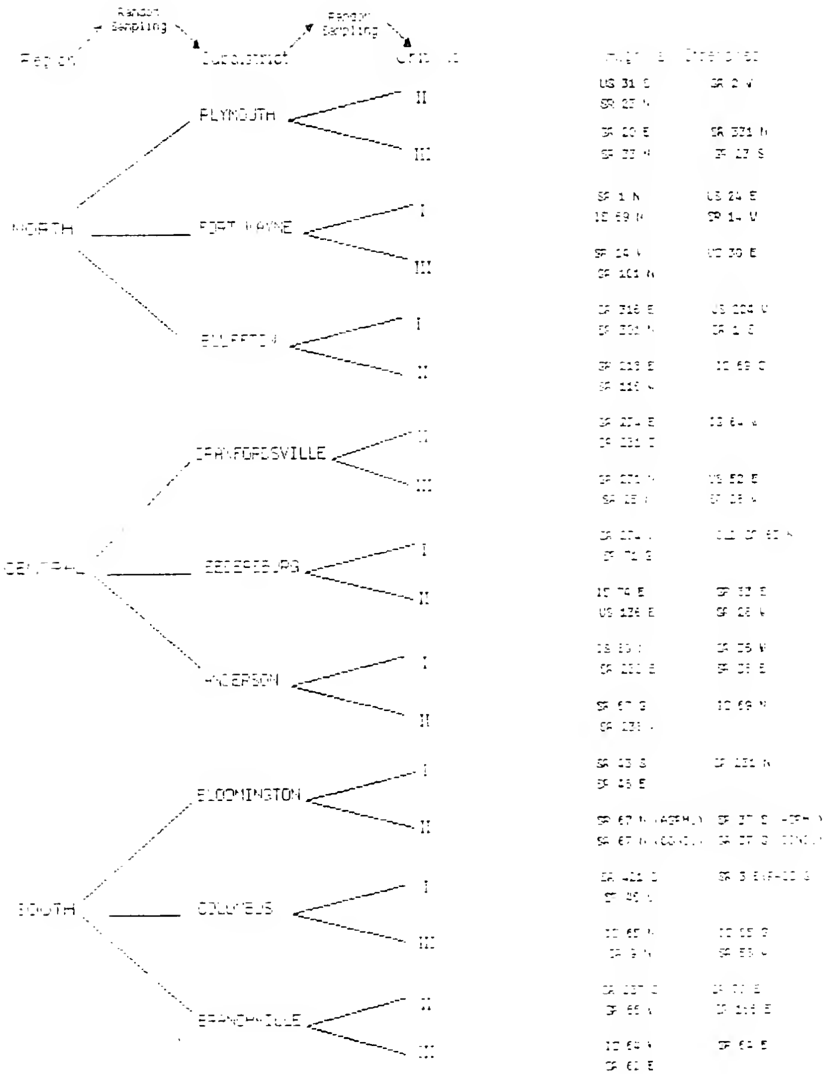


Figure 3.9 Structure of the Statistical Sampling and Highway Stretches Surveyed

evaluations was minimized.

Distresses subjectively evaluated by the unit foremen, such as potholes, were counted and physically measured; highway condition subjectively evaluated by the unit foremen, such as drainage condition, were objectively evaluated by measuring features and distresses related to them, such as width and depth of the roadside ditch, amount of ditch erosion and type of ditch cross section [35]. Figures 3.10 and 3.11 are photographs of field measurements being performed.

3.3.2.1 Measurement Procedure. To evaluate objectively the frequency and severity of highway distresses, a sampling procedure was used. Actual measurements were carried out on sample units within the highway stretches. Techniques similar to the one used are found in the literature [28].

Five sample units for concrete pavements and ten sample units for asphalt pavements were surveyed for each highway stretch. These numbers were selected since concrete pavements offered less variability in distress features than asphalt pavements, particularly since most rigid highway stretches surveyed were interstate or US highways. Thus, less sample units in the case of concrete pavements than in the case of asphalt pavements led to

Figure 3.10 Field Measurement of Edge Ruts in State Road 101 North, Fort Wayne Subdistrict

Figure 3.11 Measuring the Depth of Dropoff in State Road 62 East, Branchville Subdistrict

similar levels of accuracy in the determination of the overall extent of the highway distresses [28]. The sample units were 100 feet long in the case of asphalt pavements and 10 slabs long in the case of concrete pavements. These sample units were equally spaced along the highway stretch evaluated; however, the first sample unit was selected at random. An example that illustrates this technique, known as systematic sampling, is shown in Figure 3.12.

All typical distresses would be covered by the sampling approach mentioned above. But there are non-typical distresses that may trigger important routine maintenance work, such as localized big potholes that might not be included in the sample units selected. To overcome this problem, additional sample units, not selected at random, were used to include non-typical distresses, as necessary.

The forms used to record typical and nontypical distress data are shown in Figures 3.13 and 3.14. It can be noted that scales similar to those used by the unit foremen in their survey were used.

3.4 Chapter Summary

This chapter presented the procedure used to develop

Highway Section Length: 0.75 miles

Sample Unit Length: 100 ft

Total Number of Sample Units in Section (N) = 0.75*5,280/100 = 40

Number of Units to be Surveyed (n): 10

Interval = N/n = 40/10 = 4

Random Start = 2

Sketch of the Highway Section and the Sample Units to be Measured:

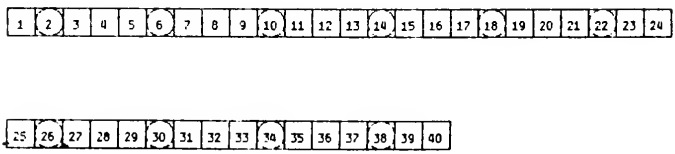


Figure 3.12 Example of the Use of the Systematic Sampling Procedure [28]

HIGHWAY CLASS & No : Typical sample unit No: length: dist:

HIGHWAY FEATURE/ DISTRESS	TRAFFIC LANES		PAVED SHOULDER	
WIDTH	1 | 2 | 3	........ft	No | Yes ......ft	...ft
SURFACE TYPE	ASPHALT	CONCRETE	ASPHALT	CONCRETE
POTHOLES	lth | wth | depth		length | width | depth	
LINEAR CRACKS	sealed | lth ..... wth	unsealed | lth<1/8 | wth	sealed | lth ...... wth	unsealed | lth<1/8 ..... wth .....
ALLIGATOR CRACKING	seal | patch L | M | H	sealed unsealed ft2	seal | patch L | M | H	sealed unsealed ft2
RAVELING	L | M | H	ft2	L | M | H	ft2
RUTTING	inside wheel in	outside wheel in	........In	
DIPS CORRUG.	DEPTH	FT2	DEPTH	FT2
BLOW UPS	L | M | H | No	FT2	L | M | H | No	FT2
SPALLING	L | M | H | No	FT2	L | M | H | No	FT2
SURFACE FAILURE	L | M | H | depth	FT2 edge?	L | M | H | depth	FT2
BUMPS	L | M | H | depth	FT	L | M | H	FT
LONG JOINTS	fault L | M | H | No	sldge LMH No	fault L | M | H | No	sldge LMH No
TRANSVERSE JOINTS	fault L | M | H | No	sldge LMH No	fault L | M | H | No	sldge LMH No
PATCHED SURFACE	L M H	FT2	L M H	FT2
LANE/SDR DROP OFF	length FT depth IN		out shder width ft	
PAVSHDR/UNPSHDR DROP OFF	length FT depth IN		med shder width ft	
BUILD UP	length FT depth IN dist from pav.shder			
POTHOLES	LENGTH / WIDTH / DEPTH		sod L M H length / shape P F G lth dpth	
DITCH	WIDTH FT DEPTH FT		REMARKS	
DIRT DEBRIS	N F S M	NO DITCH		
CLOGGED(SED.)	N F S M	CEMENT DITCH		
VEGETATION	N F S M	DITCH IN PRIVATE YARD		
EROSION	N F S M			
CROSS SECTION	GOOD (TRIANG.) BAD (SQ.)			

DAY: DISTRICT: SUBDISTRICT: UNIT:

Figure 3.13 Form Used to Record Typical Distresses During Field Measurements

DAY DISTRICT SUBDISTRICT UNIT

HIGHWAY No NONTYPICAL SECTION No

DISTRESS	MEASUREMENTS	REMARKS	Distance from Start of Highway Stretch

Figure 3.14 Form Used to Record Nontypical Distresses During Field Measurements

the proposed approach to assess highway maintenance needs. The proposed approach is based on unit foremen's evaluation of highway condition. It is recommended that the survey be performed every six months, in the fall and in the spring.

The research work included the collection of highway condition information at eighteen maintenance units throughout the State of Indiana. These eighteen maintenance units were selected by means of a stratified random sampling technique. Both subjective and objective highway condition information was collected. The subjective evaluation was performed by the unit foremen following the proposed condition survey procedure. Subsequently, the objective evaluation of the roadways involving actual measurement of distresses was carried out by the research team. The data gathered in both surveys are compared and analyzed in Chapter 4.

CHAPTER 4

ANALYSIS OF THE VALIDITY OF THE PROPOSED APPROACH

4.1 Introduction

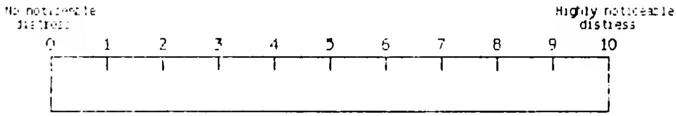
The accuracy and usefulness of the proposed approach to assess highway maintenance needs are discussed in this chapter. First, suitable models to predict maintenance work load are developed. These models are based on the foremen's rating of several deficiencies. Next, factors that influence expected work load are identified. The identification of these factors can assist in improving the consistency of future maintenance decisions. Finally, criteria are developed that relate the unit foremen's evaluation of a deficiency condition to a certain level of routine maintenance activity.

4.2 Conversion of Condition Ratings into Numeric Scale Values

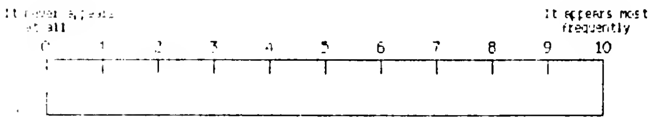
To further analyze the usefulness of the proposed maintenance needs assessment approach, the subjective condition rating data were converted to a numerical scale so that quantitative statistical analysis methods could be used. A point estimation technique was applied for the conversion of the subjective category scale used during the field survey to a 0-10 numerical scale [36, 37, 38]. This method requires that ten to twenty individuals select a point on a "variable-scale", such as a scale representing the frequency of potholes from 0 to 10, that best represents the level of the variable being asked to assess. For example, "few" potholes may mean 4.0 on a 0-10 scale to a certain assessor. Figure 4.1 shows the "variable-scales" for frequency and severity of highway distresses and for roadside ditch condition. Seventeen members of the Transportation Engineering Staff at Purdue University were requested to give representative numerical values of distress categories used during the highway condition survey. The responses to this questionnaire are presented in Table 4.1. The mean of the seventeen numerical values assessed for each distress category was subsequently adopted as representative of the category for further analyses.

Please indicate what you consider to be a representative point of the following rating categories on the numerical distress condition scale indicated:

1-Pavement and Shoulder Distress Severity: Slight (S), Moderate (M), Severe (Se)



2-Pavement and Shoulder Distress Frequency: No (N), Few (F), Some (S), Many (M)



3-Roadside Ditch Condition: Poor (P), Fair (F), Good (G)

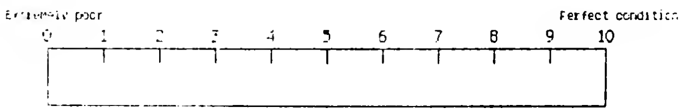


Figure 4.1 Converting the Survey Categories into Numerical Scale Values

Table 4.1 Conversion of Rating to Numerical Scales. Results of the Questionnaire

Slight	Mod.	Severe	None	Few	Some	Many	Poor	Fair	Good
1	5	8	0	2	5	8	1	5	8
1	5	9	0	1	5	9	2	5	8
1.4	5	8.55	0	1.35	5	8.65	1.32	4.95	8.55
1.45	5	8.45	0	2.5	5.45	8	2	5	7
1.45	3.65	7.88	0.7	2.45	4.45	7.82	1.27	5.15	8.87
1.5	6	8	1	3.5	7	9.5	0.5	3.5	8
1.5	5	8.45	0.15	2.05	3.95	8.45	1.45	4.1	7
1.5	5	9	1.45	4	7	9	3	7	9
1.675	5.32	8.5	0.8	1.9	4.75	8.55	2	5	8.5
2	5	8	0	2	4	7.5	2.85	5	7.45
2	4	7	0	2	3	5	3	4	6
2	5	9	1	3	6	9	2	5	8
2	4.6	6	2.1	3	4.4	7	1.65	3.85	6.15
2	4	6	2	4	6	8	2	5	8
2.4	5.42	9	0	2	3.1	6.9	1.95	4.95	8
2.55	5	8	1.4	3.9	6.15	8.32	3	6.55	8.55
3	5.55	8	0.9	3	5.5	7.55	3	5	8.65
Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
1.789	4.914	8.048	0.676	2.567	5.044	8.014	1.999	4.944	7.866
S. D.	S. D.	S. D.	S. D.	S. D.	S. D.	S. D.	S. D.	S. D.	S. D.
0.532	0.583	0.933	0.735	0.911	1.177	1.060	0.766	0.857	0.883

4.3 Analysis of the Foremen's Subjective Evaluation

There is no known published information on the relationship between the level of needed routine maintenance and roadway condition data gathered in visual field surveys. In order to develop an approximate relationship, a regression procedure was used in this study, to fit a least square estimator of the expected work load per lane mile of roadway to each routine maintenance activity based on foremen's evaluation of related highway deficiencies. The regression approach was selected because: (1) it provides an estimate of the function regressed, work load per activity in this case, that can be used to develop new Quantity Standards (QS) for prediction purposes in the future, and (2) regression allows, by means of linear tests associated with it, testing of the significance of the effects of the different variables in the equation, such as the significance of the effect of regional maintenance practices on the estimated amount of routine maintenance needed.

To perform the analysis described, all 63 roadways surveyed were analyzed together to make the tests more accurate. The underlying rationale for combining the data is listed below:

1. The roadways surveyed covered all Indiana regions, types of pavement and highway classes, and thus, the results based on all records can be considered typical for the State.

2. Normality and homogeneity of variance, required assumptions for the regression approach, were verified with the 63 records considered together. Thus, the "additivity" of the data gathered, i.e., the ability to analyze all the records together, was verified.

4.3.1 Preliminary Analysis

Table 4.2 presents the variation in estimated work load per activity when the frequency of related distresses varies from "None" to "Many" in the opinion of the unit foremen. The work loads are expressed as average work load per lane mile, shoulder mile or ditch mile, since these are the units currently used by the IDOH [11].

Table 4.2 shows that the "t" tests lead to the rejection of the equality of means hypothesis in most cases. These results indicate that, on the average, expected maintenance work load varies with the foremen's subjective evaluation of the extent and severity of related distress. Thus, it may be possible to estimate

Table 4.2 Distress Assessments and Associated Mean Work Load Estimates

Foremen's Perception of the Number of Potholes	Avge. Expected Sh. Patching (Tons per Lane Mile)	t - value	Alpha
M	5.70		
		2.720	0.005-0.0025
S+F	1.07		
		2.111	0.02-0.015
N	0.36		
Foremen's Perception of the Severity of Potholes			
Se	8.32		
		2.765	0.0075-0.05
Mo	1.25		
		1.230	0.15-0.1
Sl	0.62		

Table 4.2 (Continued)

Foremen's Perception of the Frequency of Cracks	Avge. Expected Cr. Sealing (Gal per Lane Mile)	t - value	Alpha
M	121.1		
		0.922	0.2-0.5
S+F	90.4		
		0.897	0.2-0.15
N	0		
Foremen's Perception of Cracks Severity			
Se	139.5		
		0.557	0.3-0.2
Mo	115.2		
		1.852	0.05-0.025
Sl	3.8		

Table 4.2 (Continued)

Foremen's Perception of the Frequency of Cracks	Avge. Expected Seal Coating (Lane Miles per Lane Mile)	t - value	Alpha
M	0.53		
		0.857	0.2-0.15
S+F	0.18		
		0.654	0.3-0.2
N	0		

Foremen's Perception of the Frequency of Potholes	Avg. Expected Deep Patching (Tons per Lane Mile)	t - value	Alpha
M	3.54		
		1.932	0.05-0.025
S+F	1.06		
		1.599	0.1-0.05
N	0.03		

Table 4.2 (Continued)

Foremen's Perception of the Frequency of Ruts and Dips	Avg. Expected Premix Leveling (Tons per Lane Mile)	t - value	Alpha
M	17.28		
		2.963	0.005-0.0025
S+F	9.34		
		1.233	0.15-0.10
N	0		

Foremen's Perception of the Condition of Longitudinal Joints	Avg. Expected Sealing Long. Cracks and Joints (Linear Miles per Lane Mile)	t - value	Alpha
P	0.49		
		0.774	0.3-0.2
F	0.33		
		0.331	0.4-0.3
G	0		

Table 4.2 (Continued)

Foremen's Perception of the Frequency of Raveling	Avge. Expected Shoulder Seal (Foot Miles per Foot Mile of Paved Shdr.)	t - value	Alpha
M	0.331		
		2.268	0.015-0.01
S+F	0.097		
		1.182	0.15-0.1
N	0.029		

Foremen's Perception of the Frequency of Potholes in Unpaved Shdr.	Average Expected Blading Shdrs. (Tons per Shdr.Mile)	t - value	Alpha
M	0.71		
		0.621	0.3-0.2
S+F	0.51		
		0.003	0.5-0.4
N	0.50		

Table 4.2 (Continued)

Foremen's Perception of the Severity of Shdr. Dropoff	Avg. Expected Reconditioning Unpaved Shdrs. (Shdr. Miles per Shdr. Mile)	t - value	Alpha
Se	0.63		
		3.652	0.0025-0.0005
Mo	0.12		
		1.838	0.05-0.025
Sl	0.0		

Foremen's Perception of the Ditch Condition	Avg. Expected Clean and Reshape Ditches (Linear Feet of Ditch per Ditch Mile)	t - value	Alpha
P	1068.0		
		104.068	0.0
F	231.4		
		18.561	0.0
G	121.7		

Table 4.2 (Continued)

Foremen's Perception of the Frequency of Buildup	Average Expected Clipping Unpaved Shdrs. (Shdr Miles per Shdr. Mile)	t - value	Alpha
M	0.54		
		1.588	0.1-0.05
S+F	0.36		
		5.490	0.0
N	0.02		

Foremen's Perception of the Severity of Shdr. Dropoff	Avg. Expected Spot Repair Unpaved Shdrs (Shdr. Miles per Shdr. Mile)	t - value	Alpha
Se	11.9		
		1.149	0.15-0.1
Mo	6.4		
		1.960	0.05-0.025
Sl	2.4		

Table 4.2 (Continued)

Foremen's Perception of the Ditch Condition	Avg. Expected Motor Patrol Ditching (Ditch Miles per Ditch Mile)	t - value	Alpha
P	0.06		
		0.153	0.5-0.4
F	0.05		
		0.908	0.2-0.15
G	0.02		

maintenance work load on the basis of foremen´s subjective condition evaluation. A complete analysis of the relationship between work load and foremen´s subjective evaluation is presented in Section 4.3.5.

4.3.2 Correlation between the Assessed Frequency and Severity of Distresses

The Statistical Package for the Social Sciences (SPSS) regression program was used to obtain a correlation matrix of different subjective distress frequencies and severities used by the unit foremen [39]. The records of foremen´s subjective appraisal of the distresses for each of the 63 highways evaluated constituted the input for the development of this matrix. The most significant correlation coefficients in the matrix developed are shown in Table 4.3.

Although the subjectively evaluated frequency of any particular distress was found to be positively correlated with the assessed severity of the same distress, the degree of correlation was never very high. Thus, there will not be significant problems of multicollinearity and large sampling variability of the estimated regression coefficients when performing regression analyses using the frequency and severity of the distresses as independent variables [34].

Table 4.3 Significant Correlation Coefficients between the Assessed Frequency and Severity of Different Distresses

Assessed Distress	Correlation Coefficient between Assessed Frequency and Severity
Potholes	0.50865
Cracks	0.38489
Raveling	0.40258
Rutting/Dips	0.65632
Buildup	0.47575
Potholes in Unpaved Shdr.	0.59775
Dropoff	0.65439

4.3.3 Normality and Homogeneity of Variance

The homogeneity of variance was verified with the help of the Statistical Package for the Social Sciences (SPSS) Oneway ANOVA program [39]. The homogeneity of the variance of the expected work load for each maintenance activity was verified by means of the tests due to Cochran and Bartlett and Box [40]. The homogeneity of the variance was verified over all of the possible categories of the following attributes: maintenance unit, subdistrict, assessed severity of related distresses and assessed frequency of related distresses. For example, the variance of the expected work load of shallow patching was verified across the four frequency categories of potholes, the three severity categories of potholes, and for the nine subdistricts and 18 units surveyed.

Normality of the 13 data sets was analyzed, one data set for the work load of each activity under study, by means of the Shapiro-Wilk W test [40]. Because of the properties of the stratified sampling used, normality was tested only within each maintenance unit.

A cut-off coefficient of significance of 0.01 was used to test both normality and homogeneity of variance [40]. The results of these tests are shown in Table 4.4.

Table 4.4 Results of the Tests for Homogeneity of Variance and Normality of the Data

Activity	Homogeneity of Variance	Normality	Transformation
Blading Shoulders	Checked	Checked	Square Root
Clipping Unpav. Shoulders	Checked	Checked	Square Root
Crack Sealing	Checked	Checked	Square Root
Deep Patching	Checked	Checked	Square Root
Ditching	Checked	Checked	Square Root
Full Width Shoulder Seal	Not Checked	Not Checked	---
Motor Patrol Ditching	Not Checked	Not Checked	---
Premix Leveling	Checked	Checked	Square Root
Reconstruction Unpav. Shoulders	Not Checked	Not Checked	---
Seal Coating	Not Checked	Not Checked	---
Sealing Long. Cracks & Joints	Checked	Checked	Square Root
Shallow Patching	Checked	Checked	Square Root
Spot Repair Unpav. Shoulders	Checked	Checked	Square Root

A square root transformation was applied to achieve normality and homogeneity of variance in the distribution of work load of nine activities. This transformation was applied since the variance increases with the mean, e. g., the variability of the expected amount of shallow patching was greater around its mean when there were "Many" potholes than when there were "No" potholes. The nine activities mentioned above are further analyzed in the following sections.

Normality and homogeneity of variance could not be established in the cases of Full Width Shoulder Seal, Seal Coating, Reconstruction of Unpaved Shoulders and Motor Patrol Ditching. The lack of success of the transformations tried can be explained by the fact that these activities are not frequently performed, producing erratic data sets with predominance of zeroes. Section 4.4.1 presents summary tables that show that these four activities are function of related "assessed" distresses. Apart from these summary tables, no further formal analysis to investigate the nature of these relationships was performed for these four activities.

4.3.4 Significance of the Approach

The Statistical Package for the Social Sciences (SPSS) multiple regression procedure was used [39] to

test the statistical significance of maintenance work load measured by subjective evaluation of related distresses. The SPSS package was also used to test the effect of subdistrict or individual estimator's influences on the amount of routine maintenance needs. In investigating the significance of the factors mentioned above, the following model was adopted.

$$y_i = a + \sum_{j=1}^{n_i} b_j X_{ij} + \sum_{k=1}^{9} c_k A_k + \sum_{h=1}^{18} d_h B_h \qquad (4.1)$$

where,

i = 1, 2, ..., 9 (activities in the study)

y_i = square root of expected work load per activity per lane mile, shoulder mile or ditch mile

a = independent regression coefficient

b_j = regression parameters, $j = 1, 2, \ldots, n_i$

n_i = number of subjectively rated distresses considered for each activity

X_{ij} = related subjectively rated distresses , e.g., pothole frequency, pothole severity, etc.

c_k = regression parameters, $k = 1, 2, \ldots, 9$

A_k = dummy variables that represent the subdistricts surveyed

d_h = regression parameters, $h = 1, 2, \ldots, 18$

B_h = dummy variables that represent

the estimators involved in the survey

Since the objective was only to test the significance of the different elements in Equation (4.1), no attempt was made to develop a predictive model. Interences were made from general linear tests [34], shown below.

$$F^{*} = \frac{\dfrac{SSE\ (R) - SSE\ (F)}{df_R - df_F}}{\dfrac{SSE\ (F)}{df_F}} \qquad (4.2)$$

where,

F^{*} = F statistic

SSE (R) = error sum of squares for the reduced model

SSE (F) = error sum of squares for the full model

df_R = degrees of freedom of the reduced model

df_F = degrees of freedom of the full model

The reduced model was obtained by dropping the element to be tested from the full model given in Equation (4.1). For example, the reduced model used to test the significance of the effect of individual estimators on maintenance needs assessment was as shown below:

$$y_i = a + \sum_{j=1}^{n_i} b_j X_{ij} + \sum_{k=1}^{9} c_k A_k \qquad (4.3)$$

where, variables representing the estimators were dropped

Table 4.5 presents a summary of the results obtained. It shows the significance of the proposed approach in explaining the variability of maintenance work load for eight of the nine maintenance activities considered. The lack of significance in the case of Sealing Longitudinal Cracks and Joints may be attributed to the small sample size used. Sealing Longitudinal Cracks and Joints was evaluated only on 10 concrete highway stretches surveyed.

It can be seen in Table 4.5 that maintenance subdistricts showed a significant influence in the estimation of the work load of Shallow Patching, Crack Sealing and Premix Leveling at a level of significance of 0.05. Individual estimator's influences were found significant in assessing the needs of Spot Repair Unpaved Shoulders, Blading Unpaved Shoulders and Cleaning and Reshaping Ditches. These results suggest that the amount of work in Spot Repair Unpaved Shoulders, Blading Unpaved Shoulders and Cleaning and Reshaping Ditches is particularly influenced by the personal judgment of unit foremen, while the amount of Shallow Patching, Crack Sealing and Premix Leveling are more subject to regional differences in maintenance materials, practices or standards. The influences of subdistricts and foremen should be further studied in order to achieve consistency in maintenance needs assessment.

Table 4.5 Tests for the Significance of the Approach and Subdistrict and Individual Estimator's Effects

Maintenance Activity	Approach (Related "Assessed" Distresses)			Subdistrict Effect			Individual Estimator's Effect		
	Significant at $\alpha = 0.05$	F	α	Significant at $\alpha = 0.05$	F	α	Significant at $\alpha = 0.05$	F	α
Shallow Patching	yes	6.98603 (4,41)*	<0.001	yes	2.9448 (8,50)	0.01 - 0.025	no	1.2666 (9,41)	> 0.1
Crack Sealing	yes	4.6951 (4,41)	0.001- 0.005	yes	2.5729 (8,50)	0.01- 0.025	no	1.7119 (9,41)	> 0.1
Deep Patching	yes	2.9663 (7,38)	0.01 - 0.025	no	0.8495 (8,47)	> 0.1	no	1.0688 (9,38)	>0.1
Premix Leveling	yes	2.9248 (3,32)	0.01 - 0.025	yes	2.3576 (8,41)	0.025- 0.05	no	1.7193 (9,32)	>0.1
Sealing Longitudinal Cracks and Joints	no	49.3049** (3,1)	> 0.1	no	3.5725 (4,2)	> 0.1	no	4.3236 (1,1)	>0.1
Clipping Unpaved Shdrs.	yes	25.8952 (2,43)	< 0.001	no	1.6044 (8,52)	>0.1	no	1.3799 (9,43)	>0.1
Spot Repair Unpaved Shdrs.	yes	5.9417 (4,41)	< 0.001	no	1.9063 (8,50)	0.05 - 0.1	yes	2.4455 (9,41)	0.025- 0.05
Blading Shdrs.	yes	4.2549 (4,41)	0.005 - 0.01	no	1.7162 (8,50)	>0.1	yes	4.0648 (9,41)	0.001 - 0.005
Clean and Reshape Ditches	yes	26.7146 (1,44)	< 0.001	no	1.4627 (8,53)	> 0.1	yes	3.782 (9,44)	0.001 - 0.005

* Degrees of freedom

** Remember that the sample size is much smaller in this case, thus, the power of the tests is lower.

4.3.5 Work Load and Subjective Evaluation of Distresses

This section presents the results of the regression analyses performed to relate routine maintenance work load with the subjective evaluation of distresses by unit foremen. The objectives of this analysis were:

1. To develop suitable models that can be used to predict routine maintenance needs on the basis of subjective evaluation of roadway distresses.

2. To form the basis of the calculation of "present" Quantity Standards.

3. To know how much of the variability of future maintenance work loads can be explained by foremen´s survey.

These points were addressed by a stepwise regression procedure that gives "best" models for each of the analyzed maintenance activities. The following was the model adopted.

$$y_i = a + \sum_{j=1}^{n_i} b_j X_{ij} \qquad (4.4)$$

where, all the notations were explained in Equation (4.1).

The variables listed in Table 4.6 were included in Equation (4.4) in the process of developing models to

Table 4.6 Distresses Considered in the Development of Predictive Models

Maintenance Activity	"Assessed" Distresses Considered	
Shallow Patching	Frequency of Potholes (X_1) Severity of Potholes (X_2)	Frequency of Cracks (X_3) Severity of Cracks (X_4)
Crack Sealing	Frequency of Cracks (X_3) Severity of Cracks (X_4)	Frequency of Raveling (X_5) Severity of Raveling (X_6)
Deep Patching	Frequency of Potholes (X_1) Severity of Potholes (X_2) Frequency of Cracks (X_3) Severity of Cracks (X_4)	Frequency of Raveling (X_5) Severity of Raveling (X_6) Frequency of Bumps, Blow Ups, and Surface Failures (X_7)
Premix Leveling	Frequency of Ruts and Dips (X_8) Severity of Ruts and Dips (X_9)	Frequency of Bumps, Blow Ups, and Surface Failures (X_7)
Sealing Longitudinal Cracks and Joints	Frequency of Cracks (X_3) Severity of Cracks (X_4)	Condition of Longitudinal Joints (X_{10})
Clipping Unpaved Shrds.	Frequency of Build-Ups (X_{11})	Severity of Build-Ups (X_{12})
Spot Repair Unpaved Shrds.	Frequency of Potholes in Unpaved Shdr. (X_{13}) Severity of Potholes in Unpaved Shdr. (X_{14})	Frequency of Dropoff (X_{15}) Severity of Dropoff (X_{16})
Blading Shdrs.	Frequency of Potholes in Unpaved Shdr. (X_{13}) Severity of Potholes in Unpaved Shdr. (X_{14})	Frequency of Dropoff (X_{15}) Severity of Dropoff (X_{16})
Clean and Reshape Ditches	Condition of Roadside Ditches (X_{17})	

predict work load per activity. The "best" models arrived at are presented in Table 4.7.

The values of the coefficients of determination (R^2) represent the proportion of the variability of future work loads that can be explained by foremen's surveys. The R^2 values shown in Table 4.7 indicate that foremen's evaluation of the distresses in the forms of Figures 3.4 and 3.5 can explain from 13 to 55 percent of the variability of the activities under study. Some factors that may explain the low R^2 values are: (1) the lack of full understanding by some foremen of the meaning of some distresses, like raveling, when rating the roads; (2) the lack of consistency in the speed at which some foremen evaluated the roads (10 to 55 mph); (3) the fact that some foremen rated the extent of certain distresses influenced by "non-typical" spots rather than based on the overall extent of those distresses over the highway stretches; (4) the fact that maintenance standards for certain activities are based on usage and experience rather than on established maintenance level-of-service, e.g., unpaved shoulders may be clipped once every certain few years instead of being clipped whenever the buildup is greater than a determined height; (5) the fact that some of the distresses evaluated trigger two or more maintenance options, for example, bumps may trigger either "Bumps

Table 4.7 Models for Prediction of Work Load

Maintenance Activity	"Best" Suited Models	R^2 (%)
Shallow Patching	$y' = 0.157 + 0.09253 X_1 + 0.10865 X_2$	37.15
Crack Sealing	$y' = 3.243 + 1.409 X_4$	36.54
Deep Patching	$y' = -0.362 + 0.1176 X_1 + 0.15267 X_7$	30.66
Premix Levelling	$y' = -1.339 + 0.219 X_8 + 0.459 X_9$	58.00
Sealing Long. Cracks and Joints	No significant model was developed due to the lack of sufficient sample size	–
Chipping Unpaved Shdrs.	$y' = -0.067 + 0.06746 X_{11} + 0.05793 X_{12}$	55.43
Spot Repair Unpaved Shdrs.	$y' = -0.004 + 0.21536 X_{13} + 0.26212 X_{16}$	31.30
Blading Shdrs.	$y' = 0.239 + 0.08648 X_{13}$	12.71
Clean and Reshape Ditches	$y' = 34.845 - 4.26425 X_{17}$	47.98

The variables X_1, X_2, ..., X_{17} are defined in Table 4.6

* y'= y transformed = y ** 0.5 = Square root of expected work load per lane mile, shoulder mile or ditch mile.

Burning" or "Deep Patching", depending on their severity; and (6) the fact that altogether different maintenance activities may be triggered only for a certain extent of a particular distress type and not always, e.g., raveling can trigger either sealing or patching or major maintenance, depending on the extent and severity of the raveling. It is believed that items (1), (2) and (3) can be improved with foremen training and thus the resulting future R^2 values can be increased.

A note of caution should be given. The models developed in this section are statistical in nature. No mechanistic or cause-effect relationship between work load and "assessed" distresses was established.

4.3.6 Usefulness of the Approach

Information theory considers that the value of a specific piece of information must be at least equal to the increase in payoffs resulting from the knowledge of that piece of information minus the cost of gathering such information [41]. In our case, the increase in payoffs to the IDOH due to the proposed approach is given by improvement in maintenance funds allocation decisions. This improvement would lead to lower highway life cycle cost, a value which is difficult to calculate without modeling the behavior of decision-makers. On the other

hand, the cost of implementing the approach can be divided in direct costs - one and a half days of unit foremen's time every six months - and indirect costs, the cost of processing the information that would be gathered. The indirect cost can, in a first approximation, be considered to be a minimal cost, since no extra computation facilities or personnel would be needed. Thus, considering the 115 unit foremen that would be involved for three days a year at an estimated salary of seven dollars per hour plus 22 percent fringe benefits [1], the cost of implementing this approach would be approximately 26,600 dollars per year. It is difficult to believe that reducing the uncertainty of future needs would not produce a break-even payoff of 26,600 dollars per year out of an annual budget of approximately 13 million dollars for the activities considered [1].

4.4 Analysis of the Field Survey Data

The physically measured objective condition data, recorded on the forms shown in Figures 3.13 and 3.14, had to be summarized to make possible a comparative analysis of these data with the foremen's subjective highway rating data. The forms used give the extent and severity of distresses present within sample units of the highway sections being analyzed. A computer program was developed

to extrapolate what was measured in the sample units to average values for the extent and severity of distresses per lane mile, shoulder mile or ditch mile, such as ten potholes one foot long, eight inches wide and one inch deep per lane mile. The ranges, means and standard deviations of the measurements of different distresses per lane mile of road are presented in Table 4.8.

Tables 4.9 and 4.10 were compiled using microcomputer database management software with the capability of answering "what if" questions [42], were compiled. These are summary tables and they provide an insight into the validity of the proposed approach. Table 4.9 presents the average value of the extent of different deficiency conditions when the unit foremen´s perception of that frequency was: "None", "Few", "Some" or "Many". Table 4.10 provides average dimensions for different distresses assessed by unit foremen as "Slight", "Moderate", or "Severe".

It can be observed that the "t" tests for equality of means provided in Tables 4.9 and 4.10 in most cases led to the rejection of the equality of means hypothesis at a five percent level of significance. It should be recognized that these significant differences among mean measured distresses do not assure that when a foreman rates a road as having "Many" potholes, the road will

Table 4.8 Measured Distress Ranges

Measured Distress	Ranges		Standard Deviation	Average
	Minimum Value	Maximum Value		
Number of Potholes in Lane and Paved Shdr. per Lane Mile	0	158.59	37.31	25.14
Length of Cracks (ft per Lane Mile)	304.36	15515.66	2668.72	3791.08
Length of Cracks Needing Sealing (ft per Lane Mile)	210.99	7143.84	1843.22	2951.80
Length of Cracks Sealed (ft per Lane Mile)	0	10037.30	1791.50	839.28
Area of Alligator Cracking (ft2 per Lane Mile)	0	30733.51	5375.70	3596.63
Area of Raveling (ft2 per Lane Mile)	0	36237.97	4943.47	1937.05
Area of Surface Failures (ft2 per Lane Mile)	0	686.40	102.00	30.26
Number of Slabs with Blow-Ups per Lane Mile	0	1.67	0.21	0.026
Number of Slabs with Spalling per Lane Mile	0	142.56	36.81	14.27
Length of Bumps (ft per Lane Mile)	0	171.68	36.87	17.46
Area of Dips (ft2 per Lane Mile)	0	1661.65	337.67	156.56
Percentage of Length with Rutting	0	100.00	36.12	73.81
Number of Slabs with Long. Joint Seal Damage per Lane Mile	0	528.00	77.31	23.84
Number of Slabs with Transv. Joint Seal Damage per Lane Mile	0	139.78	26.33	8.38
Lenght of Lane/Shdr. Dropoff per Shdr. Mile	0	4936.04	1338.95	2418.10
Lenght of Buildup per Shdr. Mile	0	4752.00	902.25	718.28
Number of Potholes in Unpaved Shdr. per Shdr. Mile	0	74.35	10.53	3.83
Percentage of Ditch Length with Good Cross Section (Triangular)	0	100.00	27.68	57.30

Table 4.9 Average Distress Characteristics for Different Subjective Assessment of Their Frequency

Foremen's Perception of Pothole Frequency	Actual No of Potholes Per Lane Mile Measured	t - value	Alpha
M	72.60		
		2.080	0.05-0.025
S	27.02		
		0.532	0.3 - 0.2
F	21.65		
		3.909	0.0
N	1.42		
M	72.60		
		3.773	0.0
S+F	23.30		
		2.924	0.0025-0.0005
N	1.42		

Table 4.9 (Continued)

Foremen's Perception of Cracks Frequency	Actual Length of Cracks Per Lane Mile Measured	t - value	Alpha
M	4767 ft		
		2.647	0.0075-0.005
S+F	3059 ft		
		1.813	0.05-0.025
N	499 ft		

Foremen's Perception of Raveling Frequency	Actual Area of Raveling Per Lane Mile Measured	t - value	Alpha
M	10914 ft2		
		5.421	0.0
S+F	859 ft2		
		0.243	0.5-0.4
N	765 ft2		

Table 4.9 (Continued)

Foremen's Perception of Frequency of Blow-Ups, Bumps and Surface Failures	Actual Number of Slabs with Blow-Ups Per Lane Mile Measured	t - value	Alpha
M	0.18		
		2.132	0.02-0.015
S+F	0		
		-	-
N	0		

Foremen's Perception of Frequency of Blow-Ups, Bumps and Surface Failures	Actual Area of Surface Failures Per Lane Mile Measured	t - value	Alpha
M	100.0 ft2		
		1.740	0.05-0.025
S+F	26.4 ft2		
		1.466	0.1-0.05
N	0.3 ft2		

Table 4.9 (Continued)

Foremen's Perception of Frequency of Blow-Ups, Bumps and Surface Failures	Actual Length of Bumps Per Lane Mile Measured	t - value	Alpha
M	34.5 ft		
		0.900	0.2-0.15
S+F	20.7 ft		
		2.122	0.02-0.015
N	0.1 ft		

Foremen's Perception of Frequency of Blow-Ups, Bumps Surface Failures, and Spalling	Actual Number of Slabs with Spalling Per Lane Mile Measured	t - value	Alpha
M	58.8		
		3.558	0.0
S+F	9.7		
		1.238	0.15-0.1
N	0		

Table 4.9 (Continued)

Foremen's Perception of Frequency of Ruts and Dips	Actual Area of Dips Per Lane Mile Measured	t - value	Alpha
M	731.3 ft2		
		3.293	0.0025-0.0005
S+F	164.1 ft2		
		1.873	0.05-0.025
N	9.0 ft2		

Foremen's Perception of Buildup Frequency	Actual Length of Buildup Per Lane Mile Measured	t - value	Alpha
M	1398.3 ft		
		2.250	0.02-0.015
S+F	659.3 ft		
		1.089	0.15-0.1
N	448.9 ft		

Table 4.9 (Continued)

Foremen's Perception of Frequency of Potholes in Unpaved Shdrs.	Actual No of Potholes In Unpaved Shdrs. Per Lane Mile Measured	t - value	Alpha
M	6.43		
		1.991	0.025-0.02
S+F	1.00		
		0.704	0.3-0.2
N	0.73		

Foremen's Perception of Dropoff Frequency	Actual Length of Lane/Shdr. Dropoff Per Lane Mile Measured	t - value	Alpha
M	3054 ft		
		1.003	0.2-0.15
S+F	2516 ft		
		1.397	0.1-0.05
N	1991 ft		

Table 4.10 Average Distress Characteristics for Different Subjective Assessment of Their Severity

Foremen's Perception of Pothole Severity	Actual Volume of Potholes Measured	t - value	Alpha
Se	503.3 in3		
		0.135	0.5-0.4
Mo	427.6 in3		
		1.228	0.15-0.1
Sl	140.4 in3		

Foremen's Perception of Cracks Severity	Actual Width of the Unsealed Cracks Measured	t - value	Alpha
Se	10914 ft2		
		5.421	0.0
Mo	859 ft2		
		0.243	0.5-0.4
Sl	765 ft2		

Table 4.10 (Continued)

Foremen's Perception of Raveling Severity	Actual Area of Raveling of High Severity [33] per Lane Mile Measured	t - value	Alpha
Se	1784 ft2		
		2.029	0.05-0.025
Mo	52 ft2		
		1.239	0.15-0.1
Sl	15 ft2		

Foremen's Perception of Ruts and Dips Severity	Actual Depth of Dips Measured	t - value	Alpha
Se	1.55 in.		
		4.009	0.0
Mo	0.61 in.		
		3.738	0.0
Sl	0.28 in.		

Table 4.10 (Continued)

Foremen's Perception of Condition of Long. Joints	Actual Number of Slabs with Long. Joints Seal Damage per Lane Mile Measured	t - value	Alpha
P	120.9		
		0.209	0.5-0.4
F	103.2		
		0.537	0.4-0.3
G	81.0		

Foremen's Perception of Condition of Transv. Joints	Actual Number of Slabs with Transv. Joints Seal Damage per Lane Mile Measured	t - value	Alpha
P	87.9		
		0.867	0.3-0.2
F	58.8		
		1.955	0.05-0.025
G	9.6		

Table 4.10 (Continued)

Foremen's Perception of Buildup Severity	Actual Buildup Depth Measured	t - value	Alpha
Se	1.14 in.		
		2.040	0.05-0.025
Mo	0.72 in.		
		0.615	0.3-0.2
Sl	0.59 in.		

Foremen's Perception of Dropoff Severity	Actual Lane/Shdr. Dropoff Depth Measured	t - value	Alpha
Se	1.17 in.		
		3.236	0.0025-0.0005
Mo	0.73 in.		
		0.114	0.5-0.4
Sl	0.72 in.		

Table 4.10 (Continued)

Foremen's Perception of Unpaved Shdr. Pothole Severity	Actual Volume of Unpaved Shdr. Potholes Measured	t - value	Alpha
Se	11963 in3		
		2.598	0.0075-0.005
Mo	3350 in3		
		1.325	0.1-0.05
Sl	1063 in3		
Foremen's Perception of Ditch Condition	**Actual Percentage of Ditch Length with Good Ditch Cross Section (triangular) [35]**	**t - value**	**Alpha**
P	33.64		
		2.835	0.005-0.0025
F	59.11		
		1.267	0.15-0.1
G	68.13		

always have more potholes than when it is assessed to have "Some" potholes. However, the results do show a consistent logical trend with numbers increasing from a description of "None" to "Many".

As indicated at the beginning of Table 4.9, the difference in the measured number of potholes per lane mile was not significant between roads assessed as having "Few" and those rated as having "Some" potholes. A similar lack of a significant difference between the "Few" and "Some" categories also occurred in most of the other distresses evaluated. Consequently, the rest of the analyses was conducted using a three-category scale, "None", "Some" and "Many", instead of a four-category scale.

4.4.1 Factors That Influence Work Load

This section presents a regression of maintenance work load per activity on related measured distresses. The objective was to highlight major distresses to be included in the proposed condition survey. A multiple regression procedure was used applying the following model:

$$y_i = a + \sum_{j=1}^{n_i} b_j Z_{ij} \qquad (4.5)$$

where,

Z_{ij} = related objectively measured distresses

All other variables were explained in Equation (4.1).

Table 4.11 shows highway features that were found to be significant in explaining work needs. The inferences made were based on general linear tests. It should be noted that the extent of patched surface was found to be the only additional significant highway feature that explained the variation in the estimated needs of Premix Leveling. Further tests to check the merit of including the extent of patched surface in the survey forms are presented in Section 4.5.

4.5 Changes in the Survey Forms

To check if the information on patched surface should be included in the survey forms, the following model was used.

$$y = a + \sum_{j=1}^{n_i} b_j X_{ij} + cZ \qquad (4.6)$$

where,

y = estimated work load of Premix Leveling in tons per lane mile

c = regression coefficient

Z = measured extent of patched surface in square

Table 4.11 Significance of the Explanation of Work Load by Different Measured Distresses

Maintenance Activity	Measured Distresses Found to be Significant in Explaining Expected Work Load			
	Distress	F	α	Already Included in Forms
Shallow Patching	Number of Potholes (Number/Lane Mile)	4.0879	0.025-0.05	yes
Crack Sealing	Length of Cracks Sealed (ft/Lane Mile)	4.5139	0.025-0.05	yes
	Length of Cracks Unsealed (ft/Lane Mile)	5.3057	0.025-0.05	yes
Deep Patching	Area of Blow-Ups (ft^2/Lane Mile)	8.1406	0.005-0.01	yes
	Area of Spalling (ft^2/Lane Mile)	10.5934	0.001-0.005	yes
Premix Leveling	Depth of Rutting (in)	4.3687	0.025-0.05	yes
	Area of Patching (ft^2/Lane Mile)	4.6523	0.005-0.01	no
Sealing Longitudinal Cracks and Joints	-			
Clipping Unpaved Shdrs	-			
Spot Repair Unpaved Shdrs.	Average Depth of Dropoff (in)	14.3454	< 0.001	yes
Blading Unpaved Shrds.	Number of Potholes in Unpaved Shdr. (Number/Lane Mile)	4.7097	0.025-0.05	yes
	Average Depth of Dropoff (in)	5.0975	0.025-0.05	yes
Clean and Reshape Ditches	-			

footage per lane mile

Other variables have been defined in Equation (4.1).

The SPSS [39] multiple regression procedure was used. The results obtained, shown in Table 4.12, suggest that "Patched Surface" is worth including with a level of significance of 0.01. The R^2 values with and without "Patched Surface" in the equation were 40 and 19 percent, respectively. The magnitude of this difference shows that the extent of patched surface is a good predictor of Premix Leveling needs. Therefore, this item should be included in the survey form for asphalt pavements.

4.6 Proposed Quantity Standards

The procedure proposed for use in estimating future routine maintenance needs appears to be conceptually sound; as it involves an assessment of maintenance needs based on present needs (an evaluation of distresses that trigger those needs), rather than past experience or arbitrary guesses. Furthermore, the structure of the models used in the procedure allows their accuracy to be improved with the implementation of the foreman's survey suggesting the inclusion of additional distresses or modified scales.

On the basis of the models developed in this study

Table 4.12 Role of Patching Data in the Prediction of Premix Leveling Needs

Maintenance Activity	Variables in the Regression Analysis to Predict Maintenance Activity	R^2	F* (for the significance of new variable in the equation)	Associated α
Premix Leveling	"Assessed" Frequency of Ruts and Dips "Assessed" Severity of Ruts and Dips "Assessed" Frequency of Bumps, Blow-Ups, and Surface Failure	19.13		
Premix Leveling	"Assessed" Frequency of Ruts and Dips "Assessed" Severity of Ruts and Dips "Assessed" Frequency of Bumps, Blow-Ups, and Surface Failure Measured Extent of Patched Area (ft^2/Lane Mile)	39.86	5.17005	0.005-0.01

"present" quantity standards (QS) were computed for various combinations of highway distress frequency and severity. As an illustration, the following example can be considered. The QS for Shallow Patching in roadways assessed as having "Many" "Slight" potholes was calculated using the prediction model for Shallow Patching in Table 4.7. In that model, expected Shallow Patching per lane mile is a function of the assessed frequency (x_1) and severity of potholes (x_2). The model was solved with the numerical values associated with the categories "Many" and "Slight" potholes, as shown in Table 4.1; these numerical values are 8.01 and 1.79, respectively. The resulting QS-value can thus be computed as 1.20 tons per lane mile. Similar computations were done for other activities under various combinations of distress frequency and severity. The resulting QS-values are presented in Table 4.13. These standards are proposed to be used in the implementation phase, as discussed in Chapter 5.

4.7 Chapter Summary

The analyses performed covered data from foremen's subjective evaluation and field objective measurement. To investigate subdistrict and individual evaluator's effects as well as the significance of the proposed approach, several tests were conducted on the foremen's subjective

Table 4.13 Proposed "Present" Quantity Standards

Shallow Patching
(Tons per Lane Mile)

"Assessed" Pothole Frequency

"Assessed" Pothole Severity	N	S	M
Sl	0.20	0.50	1.20
Mo	0.60	1.10	2.10
Se	1.20	1.90	3.10

Crack Sealing
(Gallons per Lane Mile)

"Assessed" Severity of Cracks

Sl	33.23
Mo	103.24
Se	212.73

Deep Patching
(Tons per Lane Mile)

"Assessed" Pothole Frequency

"Assessed" Bumps, Blow-Ups and Surface Failure Frequency	N	S	M
N	0.0	0.04	0.50
S	0.10	0.50	1.30
M	0.90	1.70	3.25

Table 4.13 (Continued)

Premix Leveling
(Tons per Lane mile)

"Assessed" Frequency of Rutting and Dips

"Assessed" Severity of Rutting and Dips	N	S	M
Sl	0.13	0.34	1.53
Mo	1.13	4.07	7.12
Se	6.27	11.96	16.89

Clipping Unpaved Shdrs.
(Shdr. Miles per Shdr. Mile)

"Assessed" Frequency of Buildups

"Assessed" Severity of Buildups	N	S	M
Sl	0.01	0.10	0.33
Mo	0.07	0.25	0.60
Se	0.20	0.45	0.90

Spot Repair Unpaved Shdrs.

(Tons per Shdr. Mile)

"Assessed" Frequency of Potholes in Unpaved Shdr

"Assessed" Severity of Dropoff	N	S	M
Sl	0.40	1.70	4.80
Mo	2.00	4.45	9.10
Se	5.10	8.60	14.70

Table 4.13 (Continued)

Blading Shdrs.
(Shdr. Miles per Shdr. Mile)

"Assessed" Frequency of Potholes in Unpaved Shdrs		
	N	0.10
	S	0.30
	M	0.90

Clean and Reshape Ditches
(Ft per Ditch Mile)

"Assessed" Condition of Roadside Ditch		
	P	693.0
	F	190.0
	G	2.0

evaluation data. The results of the tests revealed that the proposed approach significantly explains maintenance work load's variability except for Sealing Longitudinal Cracks and Joints. This is due to the fact that there was an insufficient concrete pavement sample size, because of the small number of concrete pavements in Indiana. Although subdistrict and individual foreman's effects were found to be significant for some of the activities studied, these effects were not included in the development of prediction models for the sake of simplicity.

The field measurement data helped to prove that there is a significant difference between the physical extent of most distresses and subjective ratings of these distresses. Also, field measurement data were used to test the merit of including additional distresses in the forms. These tests suggested that the extent of patched surface be included as a distress indicator, particularly for asphalt pavements. Furthermore, the statistical analysis indicated that a three-category scale would be preferable when evaluating frequency of distresses.

Prediction models were developed for estimating routine maintenance needs. These models formed the basis for calculating the maintenance quantity standards proposed in this study.

CHAPTER 5

PLAN FOR IMPLEMENTATION

5.1 Introduction

This chapter presents a summary of steps required for implementing the proposed approach. Descriptions of both the proposed survey procedure and the use of the "present" quantity standards are provided. The quantity standards may be used for both budget request and resource allocation purposes.

5.2 Implementation of the Proposed Approach

The following steps constitute the proposed approach for assessing routine maintenance needs.

1. Unit foremen would perform the developed condition survey, described in Section 3.2.1, as required for determining routine maintenance needs. Condition data would be recorded for each highway stretch within the boundaries of a maintenance unit. One

form should be filled for each highway stretch. Figures 5.1 and 5.2 show the proposed forms for asphalt and concrete pavements, respectively. These forms are modified versions of the forms used in the study. The proposed forms include "patched area" as one of the distress indicators and a three-category scale is used to describe the frequency of distresses.

2. Unit foremen would drive the whole stretch of a roadway at a reduced speed of about 30 mph before rating the highway stretch. It should be noted that the proposed survey was designed to be fast enough so that the entire highway network could be surveyed without resorting to sampling sections. In this manner, the foremen would base their judgment on the overall condition of the network within their jurisdiction. Only one combination of frequency and severity of particular deficiency conditions should be selected. For example, if a unit foreman thinks that there is extensive cracking of low severity in a highway stretch, he will circle or cross the cell corresponding to "Many" "Slight" cracks.

3. An estimation of maintenance needs for each activity and highway section can be made by matching the condition data recorded on the forms in Figures 5.1

DISTRICT ____________ HIGHWAY | S | US | IS | No. ____________

SUBDISTRICT ____________ FROM ____________

UNIT NO. ____________ TO ____________

DATE ____________ TRAFFIC | LOW | MED | HIGH |

DIRECTION | N | S | E | W |

ASPHALT PAVEMENTS				
TRAFFIC LANES AND PAVED SHOULDERS				
M	S	N	SLIGHT	POTHOLES
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	CRACKS
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	RAVELING
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	BLOW UPS, BUMPS AND SURFACE FAILURES	
M	S	N	SLIGHT	RUTTING, DIPS
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	PATCHED SURFACE
M	S	N	MODERATE	
M	S	N	SEVERE	
UNPAVED SHOULDERS				
M	S	N	SLIGHT	BUILD-UP
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	POTHOLES
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	DROP-OFF
M	S	N	MODERATE	
M	S	N	SEVERE	
DRAINAGE				
P	F	G	DITCHES	

Figure 5.1 Asphalt Pavement Form Proposed for Implementation

DISTRICT__________ HIGHWAY | S | US | IS | No.__________

SUBDISTRICT__________ FROM__________

UNIT NO.__________ TO__________

DATE__________ TRAFFIC | LOW | MED | HIGH |

DIRECTION | N | S | E | W |

CONCRETE PAVEMENTS				
TRAFFIC LANES AND PAVED SHOULDERS				
M	S	N	SLIGHT	POTHOLES
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	BLOW UPS, SPALLING, BUMPS AND SURFACE FAILURES	
P	F	G	LONGITUD. JOINTS	
P	F	G	TRANSVERSE JOINTS	
M	S	N	SLIGHT	CRACKS
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	RAVELING IN BITUMINOUS SHLDR	
UNPAVED SHOULDERS				
M	S	N	SLIGHT	BUILD-UP
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	POTHOLES
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	DROP-OFF
M	S	N	MODERATE	
M	S	N	SEVERE	
DRAINAGE				
P	F	G	DITCHES	

Figure 5.2 Concrete Pavement Form Proposed for Implementation

and 5.2 during the condition survey with the appropriate "present" quantity standards given in Table 4.13. These need quantities are function of the "assessed" levels of frequency and severity of distresses. For example, when a highway section has "Many" "Moderate" potholes, 2.05 tons of Shallow Patching for each lane mile of the stretch would be considered. Multiplying the corresponding "present" quantity standards by the number of lane miles, shoulder miles or ditch miles of the highway section, various maintenance needs for each highway section would be obtained. The quantity estimation for Crack Sealing and Sealing Longitudinal Cracks and Joints may be based on condition data gathered during a fall survey. This is due to the fact that fall is most appropriate to evaluate the condition of cracks that would influence the amount of sealing required. The maintenance needs for any maintenance unit, subdistrict, district, or the state, can be computed by adding the needs for each road section within that area. The calculated work loads can be used to estimate resource allocation at any of the maintenance levels.

4. The aggregation of all these evaluation data in each maintenance subdistrict would provide an indication

of the overall condition of the highway network within the subdistrict in a given period. These data can be used to check the effectiveness of different maintenance policies related to field work.

Since the proposed procedure enables the estimation of quantities of needed routine maintenance, it can be applied at the time of budget estimation. It can also be employed as appropriate during the year as an assessment of maintenance needed (as currently done with Form MM-236) for periodic scheduling. The approach developed in this study can be implemented in various phases.

In the first phase, the proposed procedure can be applied on a trial basis in selected subdistricts. The average characteristics for different subjective assessment of distresses are given in Tables 4.9 and 4.10. The values in the Tables can be considered as limits for defining various distress levels with corresponding quantity standards given in Table 4.13. The procedure can be implemented for about two years to ensure familiarity. Further review of quantity standards can then be made by implementing similar sample field measurements as used in the present study to reconcile differences in estimation, if any. By this approach, the new procedures can be

gradually incorporated into the current Maintenance Management System as desired.

CHAPTER 6

SUMMARY AND CONCLUSIONS

6.1 Summary of the Proposed Approach

The principal objective of this phase of the study was to develop a new approach to assess highway routine maintenance needs. Specifically designed for Indiana, this approach is based on the subjective rating of highway distresses by maintenance unit foremen. By relating to objectively measured distresses, some level of confidence may be passed on to estimates of routine maintenance needs. Routine maintenance needs are thus connected to their immediate cause, highway deficiencies. Maintenance planning and budgeting would be undertaken using estimates of maintenance quantities based on present needs determined from a procedure uniformly specified and applied throughout the State.

This study developed both the methodology to perform the proposed foremen's surveys and the criteria to relate

the subjective data obtained to certain levels of routine maintenance activities. In this connection, regression analyses allowed the development of prediction models for expected work load based on foremen's subjective appreciations of distresses. Finally, "present" Quantity Standards were developed.

The use of this method can provide decision-makers with the information and tools to monitor the condition of the highway network. A uniform basis can be introduced throughout the state for estimating maintenance needs as well as for assessing the efficiency and quality of maintenance field work.

6.2 Summary of Findings

The analyses conducted in the present study were based on unit foreman's subjective evaluation data and objective distress data measured in the field by the research team. Both the subjective and objective data were collected in sampled highway stretches in Indiana. The principal findings of these analyses follow.

1. The proposed approach was found to be feasible. An important focus of this study was to demonstrate the applicability of the proposed unit foremen's survey approach to maintenance needs assessment. Even

without any extensive training, unit foremen were capable of performing the survey. Furthermore, the proposed survey did not require much of the foremen´s time, thus minimizing possible implementation costs.

2. A uniform basis is provided for maintenance work load estimation by reducing the total variability of maintenance needs assessment. It was found that the proposed approach significantly explains expected maintenance needs for eight of the nine activities considered. The lack of significance in the case of Sealing Longitudinal Cracks and Joints was attributed to the insufficient number of concrete highway stretches sampled.

3. The proposed approach can be improved by the inclusion of other distresses in the survey forms or changing the form scales, as future implementation may dictate. For example, as a result of the analyses performed in this study, "patched surface" was added to the survey form and a three-category frequency scale was included instead of a four-category frequency scale.

6.3 Recommendations

Further investigation in the following areas is

recommended in order to utilize fully the possible benefits of the proposed procedure.

To achieve higher uniformity of judgments in future foremen's surveys, further training of the foremen in the recognition of highway defects is suggested. A manual with pictorial and word description of distresses can be a good first step in that direction.

Subdistrict and individual estimator's effects account for a significant part of the variability of some of the maintenance activities considered. Research on the causes of these effects would help to assure consistency in maintenance field work. Also, knowledge of the nature of these effects can improve the accuracy of the estimation of maintenance needs.

The same principles used to analyze the maintenance activities in this study can be used to analyze other activities. Should the regression hypotheses be verified in those cases, appropriate prediction models can be developed. Otherwise, as in the cases of Full Width Shoulder Seal, Seal Coating, Reconstruction of Unpaved Shoulders and Motor Patrol Ditching, non-parametric statistics may help to analyze the relationship between foremen's ratings and levels of maintenance activity.

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APPENDIX

CONSISTENCY IN MAINTENANCE FIELD WORK

A.1 Activities That Showed Inconsistencies

The results of regression analyses done to check for inconsistencies in maintenance needs assessment are presented in this section. General linear tests were used to test the significance of these inconsistencies. The following was the model adopted.

$$y_i = a + \sum_{j=1}^{n_i} b_j Z_{ij} + \sum_{k=1}^{9} c_k A_k + \sum_{h=1}^{18} d_h B_h + \sum_{j=1}^{n_i} \sum_{k=1}^{9} e_{jk} Z_{ij} A_k + \sum_{j=1}^{n_i} \sum_{h=1}^{18} f_{jh} Z_{ij} B_h \qquad (A.1)$$

where,

e_{jk} = regression parameter of the interaction term subdistrict-distress

f_{jh} = regression parameter of the interaction term estimator-distress

All other variables were explained in Equations (4.1) and (4.5).

When the interaction terms in Equation (A.1) are significant, equal extents of distresses lead to different estimated work loads. Although these inconsistencies in maintenance needs assessment can partially be explained by climatic and other regional differences, inconsistencies in maintenance level of service or maintenance techniques are probable. It should be noted that no unit-subdistrict interaction term was included in Equation (A.1) because such an interaction could not have taken place due to the characteristics of the stratified sampling used.

It was found that the interaction terms were significant at a level of significance of 0.05 for Premix Leveling, Blading Shoulders and Clean and Reshape Ditches. Based on this finding, further study of the consistency of maintenance techniques and level of service for these three activities is recommended.

A.2 Remarks about the Consistency of Maintenance Field Work

Some observations on maintenance field work practices were made during the course of the field survey. It is believed that these observations can help to avoid inconsistencies in maintenance policy related to field

work. A summary of these observations is provided below.

1. Different state highways are maintained according to different criteria for levels of service. For example, 100 percent of the edge break up is fixed in some highways, while in others maybe only 50 percent is fixed. The level of service criteria define the maintenance effort that unit foremen put into the roads. It appears that the criteria are assigned arbitrarily rather than on the basis of uniform standards using highway class or daily traffic.

2. There is no overall agreement among unit foremen on the meaning and possible treatment of raveling.

3. The activity, "Sealing Longitudinal Cracks and Joints" is performed by some foremen at the two edge joints as well as the center joint, while others only perform this activity at both edge joints.

4. It is a common practice not to maintain ditches that lie well below the pavement surface, but the distance below which ditches are not maintained varies greatly from foreman to foreman.

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